2017 Request for Evidence of Training Priority submissions

This document contains the Evidence of Training Priority submissions received by NERC through its 2017 Request for Evidence completed between February and April 2017.

The next Request for Evidence will be held in 3-5 years but extraordinary submissions can be made at any time should an emergent training need be identified. Information concerning how to submit extraordinary evidence outside of a Request for Evidence can be found here.

This evidence is used by NERC and its Advisory Boards to identify high priority and timely areas of training need relevant to NERC and its communities and informs decision-making concerning training investments such as Centres for Doctoral Training and Advanced Skills Training.

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Section 2: Evidence of Training Priority Submission

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1. Metabolomics 2. Bioinformatics associated with handling of environmental "omics" datasets
Please evidence the training need in this area from business, policy and/or third sector users.
The metabolomics community is developing at a rapid rate, as shown by the annual increase in the number of peer-reviewed publications during the last ten years. The global metabolomics market was estimated to be worth $565 million in 2014, and with a CAGR of 30% from 2014-2019 is predicted to reach $2.1 billion by 2019 [Metabolomics Market By Technique, Application and by Indications of Global Forecasts to 2019, Marketsandmarkets.com, report July 2019]. The development of the field is driven by (a) industries readily adopting the concept of metabolomics to drive R&D, and (b) improvements in analytical technologies and data analysis software. Metabolomics has widespread applications across the environmental, medical and biological sciences in biomarker discovery, environmental toxicology screening and drug discovery. While metabolomics is rapidly expanding it is still relatively under-represented in applications and publications in comparison to the other "omics" approaches (genomics, transcriptomics and proteomics). Factors inhibiting the growth of the metabolomics market include data complexity and lack of skilled professionals [see reference above]. To evaluate the current training needs of the metabolomics community, a global survey was recently conducted and published in association with ELIXIR UK and the Metabolomics Society [Training Needs in Metabolomics, (2015) Weber, Winder, Larcombe, Dunn, Viant. Metabolomics 11:784-786]. The results of the survey indicated that the current training facilities are not sufficient to meet the training requirements of the international metabolomics community. The key recommendations arising from this survey included: (1) Develop a series of face-to-face and e-learning training courses to fill the knowledge gaps in analytical metabolomics and bioinformatics, (2) to create new funding opportunities to build national/international networks of trainers to develop and deliver training programs.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
Industry is extremely keen for training to be developed in this area. This can be evidenced at two levels, with information obtained from the Birmingham Metabolomics Training Centre (BMTC): 1. Two companies contribute substantially to the training courses, including loaning ca. Â£1m of equipment to the BMTC to provide the platforms on which scientists can be trained. These companies are Thermo Fisher Scientific and Waters Corporation. A further company is showing interest in a similar training partnership. 2. Attendees on the courses run through the BMTC include scientists from industry. In addition, the BMTC has been requested to provide bespoke training in metabolomics to companies. In terms of policy development, again the government / regulatory communities are also calling for training in metabolomics. Two specific examples include: 1. European Chemicals Agency (and the BMTC has delivered bespoke training to this organisation in 2016) 2. UK Health and Safety Executive. Further anecdotal evidence for the need for training in metabolomics and bioinformatics (of omics data) can be realised through the huge difficulties of recruiting postdoctoral level scientists in these fields. For example, the last bioinformatician recruited to the NERC Biomolecular Analysis Facility - Birmingham (metabolomics node) took 1.25

years and 6 rounds of advertising to find a good candidate. After 1 year, and not a single appointable candidate has been found after many rounds of advertising. We urgently need to address this lack of training at PhD level.
How will the proposed training meet the identified demand for these skills from end-users?
Now that it's been so clearly recognised how poor the training opportunities are in metabolomics and bioinformatics, some institutions in the UK are developing courses. The main training centres are: 1. EBI 2. Imperial 3. Birmingham - the BMTC Existing courses are oversubscribed.
What is the scientific importance of this area to the UK Environmental Research community?
High. In 2009 the NERC recognised the importance of metabolomics to the UK environmental science community and established the NERC Biomolecular Analysis Facility - Birmingham (metabolomics node). Demand for access to that node continues to grow, as do the number of NERC funded projects requiring metabolomics. This is leading to important high impact papers, for example in the last couple of months: Regional adaptation defines sensitivity to future ocean acidification Piero Calosi, Sedercor Melatunan, Lucy M Turner, Yuri Artioli, Robert L Davidson, Jonathan J Byrne, Mark R Viant, Stephen Widdicombe, Simon D Rundle Nature Communications 8, 13994 Biodiversity in marine invertebrate responses to acute warming revealed by a comparative multi omics approach Melody S Clark, Ulf Sommer, Jaspreet K Sihra, Michael AS Thorne, Simon A Morley, Michelle King, Mark R Viant, Lloyd S Peck Global Change Biology 23 (1), 318-330 Disappointingly, due to the lack of trained metabolomics and bioinformatics experts in the UK, this NERC facility will have to temporally close on 1st April 2017 due to LACK OF STAFF. Literally all 3 postdoctoral level posts will be vacant.
What is the UK's current capacity to deliver high quality training in this area?
See above for the three major training centres in the UK (for metabolomics). The largest of these - in terms of number of courses operated - is the BMTC. The courses currently offered by the BMTC include: Face-to-Face courses 1. Introduction to Metabolomics for the Environmental Scientist 2. Environmental Genomics and Metabolomics (ENIGMA): An Integrated Course for Environmental Scientists 3. Computational Environmental Metabolomics 4. Introduction to Metabolomics for the Clinical Scientist 5. Quality Assurance and Quality Control in Metabolomics 6. Metabolite identification with the Q Exactive and LTQ Orbitrap 7. Multiple Biofluid and Tissue Types, From Sample Preparation to Analysis Strategies for Metabolomics 8. Metabolomics with the Q Exactive Online Courses 9. Metabolomics: Understanding Metabolism in the 21st Century 10. Metabolomics Data Processing and Data Analysis Again very disappointingly, course 3 (Computational Environmental Metabolomics) is already having to be closed down as we do not have the staff to teach this course. This individual left for a permanent position in the The Netherlands. In summary, metabolomics and bioinformatics are extremely exciting and active areas of science, NERC has supported this through a national service which has grown a user community and led to high quality papers. Yet the sustainability of this field, the NBAF-B centre, and training provision in these subjects is zero. In contrast, the MRC has spent £18m on building metabolomics facilities (with associated training) in the last few years, at Imperial and Birmingham.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
N/A
What would be the impact of NERC investing in a CDT in this area at this time?
N/A
What would be the impact of NERC not investing in a CDT in this area at this time?
N/A

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

2. Affordable and Clean Growth

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Following on from this weeks discussions at NERC Council Retreat, I think NERC could usefully consider scoping a CDT in "Affordable and Clean Growth" as this is one of the ten pillars in the govt industrial strategy green paper which is otherwise rather thin on environmental ideas. A CDT on this topic would position NERC well in this area, and would provide evidence that NERC are the expert/appropriate partner for other research councils on future industrial strategy challenge fund projects. It could be sensible to somehow involve other research councils in the CDT also. I'm not proposing a solution here, it just seemed to be a timely idea!
Please evidence the training need in this area from business, policy and/or third sector users.
N/A
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
N/A
How will the proposed training meet the identified demand for these skills from end-users?
N/A
What is the scientific importance of this area to the UK Environmental Research community?
N/A
What is the UK's current capacity to deliver high quality training in this area?
N/A
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
N/A
What would be the impact of NERC investing in a CDT in this area at this time?
N/A
What would be the impact of NERC not investing in a CDT in this area at this time?
N/A

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

N/A

3. Subsurface Surveillance and Modelling

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Subsurface surveillance and modelling - for CCS, water management and hydrocarbon production. This could link geomechanical modelling, laboratory measurement, reservoir simulation, seismic surveillance (4D and microseiemic) and satellite altimetry.
Please evidence the training need in this area from business, policy and/or third sector users.
Global - subsurface surveillance and monitoring is a key emerging regulatory, policy and public perception theme related to seismicity induced by human activity - e.g. Oklahoma water injection, Netherlands gas production UK - key issues for onshore unconventional oil and gas production should this become economic at scale, and offshore carbon capture and storage, should government funding for this ever be confirmed
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
Business - strong partnerships already exist with the energy industry e.g. Bristol BUMP microseismic industry consortium, Swansea/Leeds Fracgas JIP, diverse fibre optic companies in England with industry involvement and funding. There are also potential applications to mining, either current or relict. Policy - good science is necessary to inform policy e.g. the Royal Society report on shale gas https://royalsociety.org/topics-policy/projects/shale-gas-extraction/report/ Third sector - partnership with NGOs could be improved so their positions are better informed by evidence
How will the proposed training meet the identified demand for these skills from end-users?
Provide PhD's with high-end skills relevant to the industry. The only possible qualification to this is the number of jobs available in this specialist field. For example the oil and gas CDT focused on more mainstream exploration skills and, while generating a large groundswell of industry support and a large number of students, it remains unclear whether the work will be there at the end of the day.
What is the scientific importance of this area to the UK Environmental Research community?
Surveillance and monitoring of this kind has much in common with work by the UK environmental research community e.g. Ice sheet monitoring - e.g. seismic, micro seismic, radar sounding, satellite altimetry Volcano monitoring - e.g. seismic, micro seismic, satellite altimetry. microgravity A CDT could include these themes to broaden research capability beyond industrial application.
What is the UK's current capacity to deliver high quality training in this area?
The UK already has great strengths in this area - e.g. Bristol BUMPS microseismic consoritium, Swansea Rockfield spinoff and diverse JIPs for mechanical earth modelling, various fibre optic companies in England. A CDT might provide the opportunity to advance some key research and train up staff for the future. There are a few MScs in Geophysics in the UK - Aberdeen, Bristol, Leeds - which provide training in some of these areas, although student numbers may vary.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
Proven model, deep technical topics, evolving research field, synergy with other

environmental science, building on UK strengths
What would be the impact of NERC investing in a CDT in this area at this time?
Developing talent, strengthening UK's science reputation, industrial impact, environmental monitoring impact
What would be the impact of NERC not investing in a CDT in this area at this time?
Continue the current rate of progress with existing industrial JIPs and environmental research

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

I manage a Global Technology Centre (GTC) based in the UK (Aberdeen and London) for Chevron Energy Technology Company. We do global service work and R&D with colleagues in Houston, universities and service providers in the UK. This suggestion touches on some of our more interesting work, including participation in BUMPS and other related UK JIPS. I write it as an individual to provide input for your consideration, rather than as a company representative as I do not want to imply any commitment from Chevron at this point to participate or fund such a UK CDT.

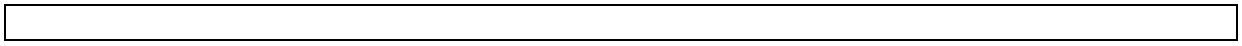
4. Oceans and Human Health

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Oceans and Human Health (OHH) The oceans can affect our health in many ways, with the health of the oceans and humans being closely linked. Interactions can be related to both negative and positive impacts on human health. As an island nation with extensive marine activities the UK has a particular need for inter-disciplinary researchers that leads to a better understanding of the interaction between the marine environment and human health. Areas of relevance to this topic include: seafood safety both in terms of health benefits and contamination of product, pollution through chemicals, radionuclides, nanoparticles and micro-plastics and their incorporation into the food chain, health promotion in the blue gym, marine bio-discovery in terms on nutraceuticals and drugs, ecosystem services via waste support of the food chain, remediation and recreation. Some critical skills and knowledge gaps include: Monitoring and surveillance techniques for chemicals, toxins, pathogens and for seafood and water safety. Understanding of transformation pathways of toxins and pathogens through the marine food chain to humans. Environmental models to determine transmission routes of disease and areas of higher risk for example in relation to pathogens, chemical dispersion, harmful algal blooms. Knowledge management systems capable of evaluating health risks from the marine environment. Methods to evaluate social and behavioural aspects and the value to human health and wellbeing of interaction with the marine environment. Climate change, natural marine events and the implications for human health. There is a need for coordinated interdisciplinary research that will build a UK OHH community with increased interdisciplinary scientific capacity with an emphasis on the development of coherent understanding, methodologies and approaches.
Please evidence the training need in this area from business, policy and/or third sector users.
There is a clear policy driver to research in the area of OHH. Safeguarding and promoting human health by reducing disease and improving the quality of the global environment are major challenges at the top of the policy agenda of governments worldwide. The European Marine Board position paper 19 Linking Oceans and Human Health: A strategic research priority for Europe outlines the importance of OHH research particularly in terms of developing policy related to human use of the sea, but also for the sustainable development of marine industries such as aquaculture, fishing and biotechnology. Other examples include the Environment Agency report of 2006 in relation to chronic aquatic ecotoxicology of human pharmaceuticals. With Moore et al. (2013) Microbial Ecology 65:889-900 highlighting the need for an integrated approach for development of effective environmental and public health policies on a regional and global scale. The importance of OHH is also highlighted in the UK Marine Statement Policy of 2011 and is highly relevant to DEFRAs Charting Progress II and Scotland's Marine Atlas in terms of a Clean and Safe Seaside. Closing of the skills and knowledge gaps will deliver more integrated science related to oceans and human health with better cross discipline linkages. Provision of enhanced scientific skills will enable society to better understand the risk and the benefits to health from marine environments and how to sustainably manage the oceans and shelf seas.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
Opportunities exist to link to policy driven research into clean and safe seas though DEFRA and Marine Scotland. Cross council collaboration with the MRC or the ERRC would also be

potentially possible. Maine industries including aquaculture and pharmaceutical companies that utilise marine resources, along with those that discharge waste into the marine environment all have an increasing responsibility to ensure the safety of their products or operations, but often lack the scientific basis on which to make business decisions.
How will the proposed training meet the identified demand for these skills from end-users?
The European Marine Board position paper 19 Linking Oceans and Human Health: A strategic research priority for European outlines a need from cross disciplinary researchers with an understanding of the role of oceans in human health. There is a clear lack of scientist with a cross disciplinary understanding of the role of the marine environment in influencing human health, this CDT will develop a community of researchers capable of addressing this shortfall.
What is the scientific importance of this area to the UK Environmental Research community?
Human health and the quality of the natural environment and both high priorities for government. However, at least in a marine context, these disciplines are frequently addressed and studied separately. Hence initiatives to focus marine environmental research relevant areas such as human health is important to ensure that environmental science remains relevant to policy drivers.
What is the UK's current capacity to deliver high quality training in this area?
Significant capacity exists in the UK in this area, but it is fragmented and currently lacks the focal point necessary to provide holistic cross disciplinary training. In addition to SAMS (HABS, micro plastics, radionuclides) other relevant institutions include PML (social policy, coastal modelling), U. of Exeter (epidemiology, micro plastics), Herriot Watt (nanoparticles), Stirling (Aquaculture), Hull and, Plymouth Universities (Aquatic environmental Toxicology).
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
There is a general lack of understanding of the breadth of issues related to the topic of oceans and human health. A CDT will therefore enable a cohort training approach to be adopted this will ensure that students gain a wide appreciation of the linkages between the marine environment and both positive and negative health issues. Peer-to-peer learning will widen cross discipline understanding.
What would be the impact of NERC investing in a CDT in this area at this time?
For the first time in the UK a CDT would bring together scientists with diverse but related interests in the theme of oceans and human health. This would help to build an oceans and human health community in the UK, provide a cohort of students trained in important issues related to OHH and ensure that they have a wide cross disciplinary understanding of OHH issues suitable for use of relevant problems in the UK and abroad.
What would be the impact of NERC not investing in a CDT in this area at this time?
OHH has been a topic of concern in the US for a number of years and recent position papers from the European Marine Board have highlighted the importance of this area of activity in Europe. With Brexit soon to be upon us it is important that the UK develops capacity in this field both for our own needs and also to ensure that we can interact on the world stage in this rapidly developing field. Failure to effectively address the issues related to OHH will adversely impact efforts to provide safe and nutrition seafood for a global population, and the availability of environmental goods and services from the marine environment. It will also negatively affect the drive for improved health and social and economic stability; and thus, will impinge on policy decisions both nationally and internationally.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.



5. Communicating Environmental Science to Non-Scientists

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Communicating environmental science to non-scientists The National Trust is a charity with a wide remit to protect built and natural heritage across England, Wales and Northern Ireland. Our ten year strategy Playing our Part identifies the following aims: restoring a healthy, beautiful and natural environment, offering experiences that move, teach and inspire, helping look after the places where people live and looking after what we've got As an end user of NERC science, the National Trust has identified Science Communication as a key area for development as part of the NERC training strategy, including the following training outcomes and skills that would help us to achieve our aims: Training Outcomes: - A detailed knowledge of the wider debates influencing environmental research in the 21st Century (e.g. climate change) and an understanding of how the students research sits within that framework; - An understanding of how environmental science is used in the third sector, and key challenges; An understanding and appreciation of the current policy context and debates for their particular area of environmental science; - A knowledge of what best practice for science communication looks like; - Student is equipped with valuable skills that will enable them to apply for jobs in a range of sectors. Skills Developed: - An ability to communicate complex scientific concepts in ways which are understandable to non-scientific audiences, both in writing and verbally; - An ability to facilitate two-way discussions between the Trust and their audiences to improve public understanding of science and engage a wide range of people in the debate; - Strong negotiation and influencing skills; - Meeting facilitation skills; - Conflict resolution skills.
Please evidence the training need in this area from business, policy and/or third sector users.
The National Trust is a heritage conservation charity that looks after 1000 square miles of land; two-fifths are protected conservation sites (SSSI or ASSI) and fifteen square miles are National Nature Reserves. We look after a range of different habitats including woodlands, fens, rivers and beaches, with the aim of supporting landscapes that are rich in wildlife, maintaining healthy soils and water, and ensuring nature is accessible for all. Our work sits within the broader framework of significant environmental challenges facing society in the 21st Century, such as climate change (including riverine flooding, sea level rise and coastal erosion), water pollution and biodiversity loss. We need to work with others (e.g. landowners, government and agencies, NGOs, the public) to tackle these challenges. The science underlying these challenges is often complex and controversial; we need more researchers with strong science communication and people engagement skills to facilitate discussions, help ensure stakeholders have a full understanding of the issues, and make informed decisions about how best to manage our shared heritage. From the Trusts perspective we have the following needs: - Improved public understanding of key environmental challenges that impact on society and the Trusts work; - Access to more researchers who can help us communicate complex scientific issues to a broad range of audiences, in different ways (via placements and/or employment); - Access to researchers who can help Trust staff to effectively discuss science with audiences and stakeholders; - Interaction with researchers who understand our science needs and practical challenges and are willing to engage with us to explore scientific solutions to these.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

Our suggestion for NERC students to gain science communication skills is through a mix of NERC-led workshops (possibly involving students from other research councils to gain different perspectives), seminars and via placements within external organisations such as the National Trust to gain practical experience and skills. Although we do not usually offer financial support for placement students, we can provide staff time and/or mentoring along with significant opportunities for students to apply their new skills to real-world situations. We have a successful track record of working with university partners on projects focused on science communication and public engagement, including our recent NERC-funded partnership with the University of Exeter, focusing on exploring climate change and natural flood management techniques with the public at Porlock Vale and the Culm/Clyst. As part of this project three researchers received training in science communication and public engagement techniques and were able to apply it to real world scenarios. This project has enabled us to engage more people in the climate change debate, and understand how it affects them personally. It has demonstrated to us the enormous value of working in partnership with researchers trained in science communication on projects based on complex and sometimes contentious scientific issues.
How will the proposed training meet the identified demand for these skills from end-users?
As an end user of NERC science, we have focused in this application on science communication skills, as this is a key area in which we have identified a Trust-wide gap in our in-house expertise. Going forward it is essential that we build up this expertise to help achieve our strategic aims through the following outcomes: - Improved public understanding of key environmental challenges the Trust is helping to address; - Improved relationships with between the Trust, other stakeholders and audiences resulting from better communication.
What is the scientific importance of this area to the UK Environmental Research community?
Scientific research underpins many of the challenges we face in the 21st Century (e.g. climate change, biodiversity loss). Being able to communicate science to non-scientists is important because: - wide dissemination of research broadens the reach of the work; - it provides a real-world context for the research; - it enables research findings to be more easily understood by policy makers and end users, enabling them to translate it into policy more effectively, maximising impact; - inter-disciplinary connections can be revealed and explored more easily, adding value to the research.
What is the UK's current capacity to deliver high quality training in this area?
We are aware that general communication skills are a component of most undergraduate and postgraduate courses and that the Doctoral Training Programmes have formalised training in communication for PhD students. In addition there are a number of excellent policy placement schemes in operation (e.g. NERC, Royal Society, British Ecological Society) which help individual researchers bridge the divide between science and policy/practitioner. Whilst these existing initiatives are excellent there is scope for reaching a much larger group of individual researchers. Furthermore, there is a subtle but important distinction between a policy and practice. Most current training initiatives are focused on science-policy communication rather than links to practitioners.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
N/A
What would be the impact of NERC investing in a CDT in this area at this time?
N/A
What would be the impact of NERC not investing in a CDT in this area at this time?
N/A

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

The National Trust has identified additional training priorities/needs: Interdisciplinary working: More cross-disciplinary work to promote creative thinking skills and understanding of broader context of own research (example: PhD students from science, social science backgrounds hold a workshop with organisations to explore key environmental science issues e.g. climate change, environment & health). Science-based archaeology: Remote sensing data collection and analysis to detect unrecorded archaeological remains on NT land and monitor asset condition in light of climate change, coastal erosion, vegetation, animals and visitor impacts upon archaeological sites to address the lack of detailed/long term understanding of asset condition. Ecology, biodiversity and systematics: There will always be a need for good taxonomists as there are gaps for many of the more difficult groups (invertebrates, fungi, lichens, algae) knowledge of which is critical for fully understanding species abundances, diversity and distribution across NT land holdings. Population genetics and evolution: Collection, analysis and interpretation of long term datasets (plants/animals) (e.g. by embedding more PhD projects into NT long term studies) for improved understanding of plant/animal response to climate change. Hydrogeology Hydrogeology skills are needed both within the Trust and more widely (statutory agencies, consultancy) to help us understand the impact of major developments (e.g. High Speed 2) and emerging industries such as fracking. Pollution, waste and resources: Knowledge of technology and methods for effectively and sustainably dealing with waste streams (e.g. removing and recycling phosphate from sewage). Water quality measurement and modelling: Monitoring skills (including selection of appropriate chemical markers), analysis and interpretation of results are needed for improved understanding / quantification of NT aquatic assets to inform NT policy and practice.

6. Digital skills for data intensive global change research

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Digital skills for data intensive global change research - analysis of responses to the survey indicated that priority challenges and the skills most in need of improvement are: Data complexity, Data standards, Data discovery, finding relevant and potential data sources, Data management, Overcoming barriers to data sharing, including cultural and interdisciplinary issues, Improving programming and data analysis workflow, Improving computational and numerical analysis skills Survey conducted Nov and Dec 2016 (160 respondents) and report finished this week. https://drive.google.com/drive/folders/0B7P9mLnLrf3nUHB6YmEwNGVjZDg
Please evidence the training need in this area from business, policy and/or third sector users.
Survey conducted Nov and Dec 2016 (160 respondents) and report finished this week. Report funded by NERC via involvement with Belmont Forum. https://drive.google.com/drive/folders/0B7P9mLnLrf3nUHB6YmEwNGVjZDg
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
N/A
How will the proposed training meet the identified demand for these skills from end-users?
N/A
What is the scientific importance of this area to the UK Environmental Research community?
N/A
What is the UK's current capacity to deliver high quality training in this area?
N/A
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
N/A
What would be the impact of NERC investing in a CDT in this area at this time?
N/A
What would be the impact of NERC not investing in a CDT in this area at this time?
N/A

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

N/A

7. Tropical Biomes

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
There is an urgent need for a cohort of scientists with skills in quantifying, monitoring and valuing the resilience and sustainability of tropical biomes. This training area would encompass diverse disciplines including ecology and biodiversity science, social science, ecological economics, and agricultural science, united under a theme that emphasises the teaching of quantitative methods for evaluating competing human and natural values. Tropical biomes are the global foci of habitat destruction, agricultural expansion and human population growth, are where the conservation status of vertebrate species is declining most rapidly, and where species are most sensitive to future climate change. Tropical forests alone contribute 1.5 billion livelihoods and house half of terrestrial biodiversity and above-ground carbon, yet cover just 10% of the worlds land area. Achieving a desirable, sustainable future for people and nature in this globally important biome represents one of the key challenges in global development. Fundamental to managing change is measuring it and making informed decisions to trade-off one concept of value against others. Concepts like resilience, to short term and chronic disturbances, and sustainability, are qualitative and represent desirable development goals, but quantitative, measurable definitions are rare. Rarer still are metrics that define the value of resilience and sustainability. Key to developing solutions to this problem is developing a cohort of students with training in thinking quantitatively about concepts that do not easily boil down to numbers (e.g. resilience and sustainability), experience in combining metrics to develop quantitative indices with desirable properties, understanding of how to evaluate multi-dimensional trade-offs among key variables from alternative disciplines, and awareness of how to implement complex trade-offs in policy and in practice.
Please evidence the training need in this area from business, policy and/or third sector users.
This training need is consistent with the UK Governments Global Challenges Research Fund, and with the associated RCUK challenge areas that were developed with DFID and with reference to UK Aid Strategy and the UN Sustainable Development Goals. UK international aid is focussed heavily on supporting the sustainable development of nations that predominantly occur in tropical regions, and implementing solutions to RCUKs list of development challenges will require trained personnel with the ability to make defensible decisions about complex trade-offs.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
A training program on this area has potential to develop a broad set of partnerships. The cohort of students will emerge with the skills needed to implement solutions to development challenges. Governmental and non-governmental development agencies could be approached to provide real-world case studies to form the basis of individual PhD projects, and potentially to help introduce students to specific development challenges through targeted short courses. Businesses with interest in tropical biomes, particularly in the agricultural industry, are under pressure to conform to ever-increasing standards of environmental sustainability and corporate responsibility, for which the ability to manage complex trade-offs is an important skill, and could reasonably be approached to invest in the training programme.
How will the proposed training meet the identified demand for these skills from end-

users?
NERCs Most Wanted report (2012) surveyed the environmental services sector to identify critical skills gaps. Training on this area would emphasise the three key skills gaps of multi-disciplinarity, translating research into practice, and sustainability science and planning, gaps not currently the focus of existing CDTs, while providing ancillary training on a further five cross-disciplinary skills (modelling, data management, numeracy, fieldwork, risk and uncertainty). Individual students within the cohort will, depending on their project topics, have further opportunity to develop expertise in another six discipline-specific skills (soil science, environmental epidemiology, microbiology, food supply, energy supply and freshwater science).
What is the scientific importance of this area to the UK Environmental Research community?
Large swathes of the UK environmental research community are already actively engaged in research in tropical nations, and the UK is a world leader in understanding and modelling tropical systems, one of the reasons NERC has been so well placed to respond to the GCRF, and many others are now directing their research in this direction as a response to GCRF priorities.
What is the UK's current capacity to deliver high quality training in this area?
The UK has high capacity for training in this area. There are multiple institutions with strength and depth in research focussed on tropical biomes, each encompassing one or more strengths in relevant multidisciplinary sciences (e.g. conservation), environmental sciences (e.g. ecology, climatology), economics (e.g. ecosystem services valuation) and agricultural sciences (e.g. crop breeding, pest management).
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
Practical experience is key to developing a cohort of students with the necessary skills in this area, and the most appropriate form of training in which to accumulate that experience is as part of a Doctorate. Entirely and/or predominantly course-based training, either in undergraduate, MSc or short course formats may give adequate background to the issues involved, but is unable to provide the hands-on experience of developing quantitative solutions to development challenges. Giving students training and experience of multiple scientific disciplines requires a CDT style format, which comes with three advantages for inter-disciplinary training: (1) All students can be passed through a compulsory set of introductory short courses introducing them to multiple disciplines. Students could be provided flexibility to choose from a required minimum number of courses, ensuring training meets their interests as well as the wider needs of the training programme. (2) It can be stipulated as part of the CDT that all students have supervisors from two or more disciplines, ensuring that only interdisciplinary projects are undertaken. (3) Cohort building among CDT students provides a route for all students to engage with, and be aware of, research being conducted by their peers in disciplines outside of their own.
What would be the impact of NERC investing in a CDT in this area at this time?
The next 50 years will see an increase in human population size, levels of consumption, poverty, species extinction and global temperature. These changes will most dramatically impact tropical regions. If we are to halt such changes we need to train personnel who are able to deal with multidisciplinary information, who have first-hand experience of doing field research in tropical countries, and who are able to communicate to policy makers and industry the key policy and management priorities.
What would be the impact of NERC not investing in a CDT in this area at this time?
We would lose the opportunity to leverage a large quantity of active research projects in tropical nations that will be funded through GCRF in the immediate future. Sustained failure to invest in this topic would risk the UK losing its position as a global leader in tropical sustainability science.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

8. Computing and Earth Sciences

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Computing and Earth Sciences: Computing has become central to nearly all areas of human activity but, within science, software encapsulates knowledge and enables widespread scientific, policy and business application of that knowledge. This is achieved through modelling software (from volcanic hazards to oil-field evaluation) or data analysis (from geochemical analysis to big-data based studies of earthquake risks). NERC already funds CDTs in big-data analytics (in risk mitigation) and computer modelling (in ecology) and it is time that similar training opportunities were available to Earth scientists who rarely have formal training as computer scientists (or vice-versa). Furthermore, computer and Earth scientists use technical languages which make their insights virtually impenetrable to outsiders interested in building links. The result is a serious shortage in industry, government, NGOs and academia of personnel capable of developing disruptive computing tools that utilize knowledge from the cutting edge of both computing and Earth science. A CDT is required that addresses this issue by offering Earth science projects, jointly supervised by computer-scientists and Earth scientists, targeted at problems important for progress in industry, sustainable development and in science itself. Core involvement of IT professionals is not offered by any existing CDTs. Specific computing skills would be in areas such as: programming languages, numerical modelling, databases, parallel programming, big-data analysis, instrument software, human-machine interfaces, information security and machine learning. Earth-science skills could cover the entire field but would be concentrated in areas such as: mineral exploration, natural hazards, geochemical analysis and environmental protection.
Please evidence the training need in this area from business, policy and/or third sector users.
I am frequently approached by industry representatives searching for post-graduate personnel with this skill combination. I also know of industry-led projects that folded for lack of appropriate personnel (e.g. Turbidity current modelling at Midland Valley which collapsed when no replacement could be found for a departing programmer). Within the UK, there has been no training in Earth-Sciences and Computing since NERC withdrew funding from an MSc at Keele University 20 years ago. Those of us interested in this research area offer our own computer science training but being taught such skills by people who are themselves self-taught programmers is a recipe for perpetuating inefficient, out-dated approaches. A major software company sent the following letter when I inquired whether they would support this CDT: Subject: Supporting proposal for Centre of Doctoral Training Earth Science as a discipline is reliant on the collation and interpretation of large and often disparate datasets. The ability to mathematically interrogate these data using rigorous and robust methods is often overlooked in the training of undergraduates and post-graduates in the Earth Sciences; yet these skills and their application have an increasingly important role to play in the future development of our science and particularly for the Energy Sector. The application of modern computer science methodologies, such as machine learning or multi-dimension modelling, to Earth Science problems can lead to significant discoveries and generate new insights from existing datasets. Halliburton-Landmark recognises the shortage of talented graduates with a combined earth and computer science skillset. As such Halliburton-Landmark would welcome the establishment of a Centre of Doctoral Training to address this shortage and foster utilization of data and computer science techniques within Earth Sciences. Nagaraj Srinivasan Senior Vice President, Landmark Halliburton Energy

Services Inc
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
Earth-science departments have extensive links with the oil industry a major user of software and data and I anticipate that funding, project-suggestions, data and software will be obtained from that source (ES at RHUL has received ~£1 million per year of industry funding for 20 years along with free industry data and software). The oil-services sector (e.g. geophysical exploration companies and oil-related software companies) have not traditionally provided much academic funding but would support a CDT in this area through sharing of expertise, software and data as well as through funding at the relatively low cost associated with large consortia that a CDT could attract. This would be distinct from, but complimentary to, research projects undertaken by the existing CDT in Oil and Gas which has a focus on solving geological-problems rather than on development of new computer-based techniques. There is also scope for development of computing techniques in the mining sector which has lagged behind the hydrocarbon industry in utilization of such tools. Mining (e.g. for rare Earth elements) is central to sustainable development, economic well-being and the wide-spread introduction of green technologies (e.g. components for batteries, wind-turbines and solar cells). Computer-based techniques are similarly vital for nuclear-waste disposal, geothermal energy and carbon-capture and storage. All these sectors would benefit from involvement in a Computing in Earth-Sciences (CES) CDT whether through funding, making available software and data or suggesting suitable projects. Finally, there is increasing scope for applying mobile technologies (e.g. apps on smartphones) to natural hazards (e.g. we are currently developing apps that model pyroclastic flows) although there is overlap with existing CDTs in this area.
How will the proposed training meet the identified demand for these skills from end-users?
Graduates from a CES-CDT would have the skills to build efficient, well-designed software tools based upon in-depth understanding of Earth processes and in-depth understanding of Earth scientists. Training would be of two distinct types: (i) Training Earth-Science graduates in computer science; (ii) Training IT graduates in Earth science. Either (but ideally both) routes would produce PhDs with a high degree of competency in the two fields. One interesting possibility would be to set up a buddy system in which an Earth-Science student and a Computer-Science student were paired up and expected to work together on related projects under the joint supervision of an Earth-Science academic and a Computer-Science academic. This would force cross-fertilization and inter-disciplinary communication. There is no easy way to set up such PhD projects within the existing RCUK framework. Graduates from such a programme would not only have excellent computing and Earth science skills; the experience of working in such strongly cross-disciplinary projects would provide them with invaluable soft-skills such as the ability to feel at home in multi-disciplinary teams and the ability to retrain more easily when their future career-paths require it.
What is the scientific importance of this area to the UK Environmental Research community?
There is almost no area of current Earth science research which is not strongly dependent upon computer software. Progress in all science is strongly driven by new data resulting from new tools and, because of the innate complexity of the systems we study, Earth science constantly requires new software tools to analyse, integrate and model this. In reality suitable tools rarely exist and, as a direct result, the knowledge-potential of new methodologies takes decades longer to develop than it needs to. The provision of future PGRAs with strong, combined IT/Environmental-science skills would therefore give UK research a significant advantage over its competitors. Hence, strengthening the computing skills of Earth scientists would be likely to boost productivity in all areas of UK environmental research.

What is the UK's current capacity to deliver high quality training in this area?
Nearly all research-intensive universities in the UK that have an Earth Science department also have a Computer Science department. It is simply necessary to provide a funding framework which encourages them to collaborate. Better still, this framework should require collaboration between institutions to ensure the widest possible choice of subjects and, hence, to attract the best possible students regardless of their particular interests. In addition, many UK departments (including my own) have a strong research background in computer modelling and/or quantitative analysis of a wide variety of different datasets taken from across the Earth sciences. A well-structured funding opportunity should therefore attract competitive, well-thought-out bids from a significant number of high quality institutions, and would lead to world-beating training in these skills.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
This is not a training area that can be delivered by a single, small group of individuals. Making it as successful and disruptive as possible will require collaboration across disciplines (i.e. Earth science and computer science) and across institutions (to give project scopes maximum breadth). A broadly based training centre will also ensure that additional funding streams are efficiently tapped as well as sources of project ideas, datasets and software. As previously mentioned, there is no easy way to set up PhD projects that cross research-council boundaries within the existing RCUK framework
What would be the impact of NERC investing in a CDT in this area at this time?
The resulting, highly skilled PhDs would be highly employable and would be in a position to support major innovations across the environmental sciences. There are no alternate investments which would give major benefits across such a wide range of fields and do so across academia, industry and all other sectors.
What would be the impact of NERC not investing in a CDT in this area at this time?
Development of cutting-edge modelling and data-analysis tools in environmental science requires resources that are easily available to almost anyone, anywhere except for one resource; people with the right training. At present the UK competes well in the development of such software and is a major exporter of Earth-science-based computer tools. However, we will not maintain that position unless we step up to the next level before our competitors do so.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

9. Landscape Restoration

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
There is a need for environmental science graduates who understand how to restore derelict or degraded landscapes and ensure that the restoration maximises the ecosystem services than can be offered, implementing green infrastructure where appropriate to achieve this goal. Skills would need to be developed in all areas of landscape characterisation and restoration. All students should receive training in fundamental underpinning knowledge bases e.g. how to undertake and assess environmental impact assessments; aspects of planning and law particularly relevant, for example, the creation of orphan funds for landscape restoration; the important of ecosystem service and the role that green infrastructure has to play in supporting this. Thereafter the training needs could be very diverse, from developing skills in remote sensing and aerial surveying to produce maps of potential restoration solutions and their ecosystem services, to complex hydrochemical analysis coupled with geophysics to delineate pathways of pollutant transport, to the estimation of C sequestration within new soils that are being created as a land is restored, to how to consult with stakeholders and appraise project proposals with the public involved. I know of no training opportunity that brings the core research skills together with underpinning skills of relevant to landscape development and its restoration.
Please evidence the training need in this area from business, policy and/or third sector users.
Land restoration is complex as can have multiple stakeholders, and I am certain would be willing to be involved in such a CDT. For example the restoration of derelict coal mining and quarries can have the following stakeholders, who need to interact and so graduate with the skill base to connect and harmonise interests and provide an understanding that is tangible to stakeholder would be very welcome: The land owner (may not be the quarrying company) - will want to know how best to remediate any problems and restore the land best The quarrying company if retaining rights on the land may be interested in restoration that could allow further development with mineral An insurance company if the extractive industry has gone bankrupt and there is a bond to be paid for the restoration The liquidators who have responsibility for management of the process until handed over. The local community who live in the area, want to know they have a high functioning landscape again Any regulatory bodies who are responsible for the quality of the environment, air, water, land and biota want to know the best techniques and approaches for measuring, mapping and model NGOS who may be in receipt of the restored land or enter into a partnership with the land owner, insurer, liquidator, regulatory bodies, would be particularly interested in the ecosystem services conferred after restoration that may support their conservation objectives. Academic stakeholders may consider the land has research potential. For example BGS are keen to promote the open cast coalmine Spireslack as a Geopark believing there is a significant research and training opportunity.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
Any of the example stakeholders listed above could be part of the CDT as partners and this could be developed if this CDT topic was developed by the parties who would bid to host this CDT. To be more specific, I can evidence my own research here as examples of the opportunities to create partnerships., noting this is an example from one person and with ~ 50 supervisors expected for a CDT this stakeholder list could be extensive, and so the

partnerships. The following two environments which have been changed by man's activity and both require restoration: - currently I research fugitive methane emissions from springs from coal mines after hydrological rebound after the industry had collapsed. New soil is being created from sewerage sludge and this may be the source of the fugitive methane and not the coal mining. Stakeholders in this research, albeit yet to fund it are: Hargreaves (the receiver), Scottish Mines Restoration Trust, SEPA, Scottish Coal, the local community - I am currently funded by SNH and SEPA to consider the environmental impact of turbine repowering which may mean removing the existing turbine bases and restoring the sites (9000 m3 of material removed). Additional stakeholders in this research so involved in this project are SSE, Scottish Power, Zero Waste Scotland and Arup.

How will the proposed training meet the identified demand for these skills from end-users?

It would be impossible to implement a CDT on landscape restoration and maximising ecosystem services, including from green infrastructure, without end-user organisation collaboration. This means that research projects for training PGR would be co-designed and so the skill base the end-users require would be intrinsic to the thesis. We would also consult with professional bodies (e.g. Chartered Institute of Water and Env. Management) to ensure that core skills were part of the training programme all students must undertake.

What is the scientific importance of this area to the UK Environmental Research community?

We have a responsibility to ensure we invest as heavily in ensuring the landscapes we have used that are now derelict, (whether for energy provisioning, heavy industry or even housing that has been demolished as three examples), function well and contribute to a sustainable environment. We have produced graduates who may have skills that could be transferable to the challenge of reinstating an environment but have not offered this focus. To understand the challenge of reinstating a derelict or degraded environment, the practitioner has to also understand a healthy environment. However, there are skills particular to environmental restoration, that are unique to this consideration and so training in this dedicated area is needed and not just the transfer of graduates from related disciplines. From the research proposals I see in the discovery science panel and at Science Board there does not seem to be the same focus on anthropogenic landscapes (urban, derelict) and I think this is a failing*, as these too are our environment and if the research community were behind these less sexy landscapes as they are with iconic other systems, considerable advances would be made and the UK would have a better quality environment. Further, this is an area that will employ more graduates than iconic landscape research, where students post graduating would tend to have to stay in academic research (~ 5% of graduates). However this CDT is also important for support of environmental science worldwide, with likely parallels between research projects here and some aspects of the global challenges that we are being asked to address in developing countries. Undoubtedly the focus on this topic in this CDT and the stakeholder interaction particularly will create opportunities. *I note there are good innovation funding calls that are highly applied, but not yet on landscape restoration.

What is the UK's current capacity to deliver high quality training in this area?

I think there are students who graduate who have some of the skills (e.g. portfolio contaminant analysis, GIS applications, hydrological skills, some modelling of pollutant transfer pathways). But they will not have been trained as part of a cohort whose vision is to ensure a landscape is restored to maximise ecosystem services and thus be in a position to offer that aspect of co-design in both development and restoration plans. In addition as we move to a position of non-EU membership and the associated legislation redevelopment there is new learning required and the development of those who approach an environmental management with research training. There is no post-BREXIT skill base currently. Thus we have the challenge but matched I consider by academic breadth who could come together for this new focus. Thus I think we have the capacity.

CDT Specific Information – please complete if you identify this training area as suitable for

CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
It will bring a cohort of students together with a common goal to understand the research needed to ensure landscapes are restored to maximise ecosystem services. The students will work on diverse research challenges and sites, but through-cohort based activities will learn about other restoration challenges and the skill sets needed and so the whole will be greater than the sum of the parts. The cohort approach also means that core skill training efficiently is possible, there will be peer support during difficult times and investment in training will be financially efficient: multiple stakeholders may have the same problem, and the same problem can be approached by different techniques and so there will be greater advances.
What would be the impact of NERC investing in a CDT in this area at this time?
High. We have significant restoration challenges (mining, what to do with sewage sludge, HS2, unconventional hydrocarbon extraction, wind farms) and there are political complexities that mean we may be recreating standards of environmental sustainability through for example BREXIT.
What would be the impact of NERC not investing in a CDT in this area at this time?
We would not be developing an agile cohort fit-for-purpose in a new political environment. Our landscape would continue to be a 'mess' with degraded ecosystem services, particularly in areas of little political significance which is unjust. We would lose an agile cohort of future scientists who could use their training in landscape restoration to ensure new developments are designed with sustainability and restoration in mind. This would minimise loss of ecosystem services and reduce one component of the anthropogenic pressure on such losses.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

This CDT differs from the current call for energy extraction and it focuses on post-disturbance, and particularly there are benefits in realising restoration that would feed into extraction planning / infrastructure implementation. It would be synergistic with other proposals that are related to planning and environmental legislation. Possibly less so with agriculture as these do not constitute derelict land and their sustainability has received investment via other routes e.g. STARS CDT. Urban systems would be part of this, but we also are sorely lacking training (and research) in urban science and so this could stand alone.

10. Facilitating Engagement with NERC Science

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Equipping environmental scientists with deeper understanding of public involvement Science is challenged by a current disengagement, distrust and even rejection of evidence by the public, including high profile politicians. There is an urgent need to equip environmental scientists with the understanding and tools to reach the public to transform scientific consensus into individual behavioural change and societal, economic and political commitment (Lorenzoni et al. Global Environ Change 2007;17). More training is needed to produce scientists who are not only experts in the environmental sciences but also understand how to effectively involve the public more extensively throughout the research process to increase the relevance, acceptability, impact and profile of NERC-funded research and public interest in it. Public engagement has been identified as a core priority for NERC for 2017, and NERC encourages co-design of research with users through the pathways to impact mechanism on grants, but this assumes researchers already have the capability do this. We propose that NERC must specifically invest in training in and exposure to rigorous approaches to effective public involvement and impact pathways. Training outcomes: 1) Extending capabilities for public involvement in research in order to help scientists understand the interests and concerns of different publics and support public understandings of projects or programmes of work. 2) Extending capabilities to establish public involvement and co-production processes, throughout design, execution and dissemination stages. 3) Training to appraise qualitative methods used to understand peoples interests, behaviours and experiences. 4) Training in qualitative evidence synthesis so that scientists can use existing research to understand the above. 5) Training in the contribution of theories of behaviour change, policy analysis etc. to understand why behaviour change and decision-making processes are difficult
Please evidence the training need in this area from business, policy and/or third sector users.
Public includes communities, industry, NGOs and policymakers. Science-policy gap: Contemporary urgent complex challenges (e.g. climate change, flooding and food security) require concerted and financially substantial commitments from both policy and business. Public funding increasingly requires evidence-based policymaking (https://www.gov.uk/guidance/what-works-network); business equally needs to cautiously evaluate business cases for best value. Yet the use of evidence may be politically challenged. In turn, the research community is tasked by funding bodies to contribute to this evidence gathering and synthesis with carefully planned pathways to impact (www.rcuk.ac.uk/innovation/impacts/). While there is a large body of research to investigate how to narrow the science-policy gap, the field of knowledge exchange and public involvement is rapidly evolving and suggesting that novel approaches and interdisciplinary perspectives could enhance current and persisting shortcomings (Greenhalgh, Milbank Q. 2010;88). Identified gaps suggest that beyond science communication techniques, there is a need to understand the contexts in which scientific evidence would be used, in other words to understand complexities of policy processes and political decision-making (http://www.invo.org.uk/; Strassheim et al, Evid Policy 2014;10). Value-action gap: The third sector is equally invested in improving public trust in science, and in understanding how best to affect societal commitment toward environmental protection and action. What is needed is insights into people's aspirations and circumstances and into the larger societal changes that shape social norms and socio-cultural responses to scientific knowledge. Social psychology

and sociology have developed explanatory models and frameworks to understand why values and attitudes do not necessarily translate into action; these insights are increasing applied to environmental research (Kollmuss and Agyeman, Env Edu Res 2002;8)

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

Despite recent high-profile scepticism about evidence, government is seeking to engage with scientists, e.g. through frequent evidence inquiries of parliamentary select committees (https://www.publications.parliament.uk/pa/ld201012/ldselect/ldsctech/179/179.pdf), and policy-science pairing schemes, popular opportunities to learn about each other's constraints in research, policy and practice (https://royalsociety.org/grants-schemes-awards/pairing-scheme/). Bridging the culture gap between policymakers and scientists and to broaden the disciplinary boundaries for evidence provides avenues forward (Future Directions for Scientific Advice in Whitehall: http://www.csap.cam.ac.uk/media/uploads/files/1/fdsaw.pdf). While interactions of this kind are fruitful, a concerted research effort would accelerate NERCs environmental science research impact beyond successful case studies. In our own (Guell et al, BMC Public Health 2017;17) and others public health research, policymakers and elected politicians as well as representatives of the private and third sector committed to be research participants in policy analyses to contribute to a more rigorous empirical process to improve implementation (Petticrew et al, J Epidemiol Community Health 2004;58). Qualitative research methods open a dialogue with participants and institutions that often extend the immediate research process. Research methods and mechanisms for public involvement, in particular, invite NGOs and communities into all stages of the research process and take ownership of its outcomes, this helps restore trust in science (Buckstrand, GEP 2003;3(4); Wimpenny, 2010;Participatory action research, in Savin-Baden & Major Routledge). Finally, industry efforts for social responsibility also have opened up opportunities for the co-production of knowledge between the business sector, publics and scientists (https://www2.deloitte.com/content/dam/Deloitte/fi/Documents/strategy/Make%20it%20m%C3%A4rkbar_final.pdf).

How will the proposed training meet the identified demand for these skills from end-users?

An increasing disconnect between science and the public, perhaps accelerated in the current political climate, is a concern across the scientific community (Brody et al. Environ Behavior 2008:40). Impactful research beyond the generation of scientific evidence is a vital and increasingly central function of the scientific endeavour. Investing in the training of NERC scientists with interdisciplinary and mixed-method skills, together with understandings about mechanisms of involving the public with environmental science research, can significantly help reverse the trend of science scepticism, and would, furthermore, open up opportunities for innovative research fields and cross-council funding. This training priority would provide skills beyond public engagement techniques and expose those environmental scientists with an interest in achieving public involvement, co-production and behaviour change, to relevant and rigorous qualitative and participatory research methods (Brown, Environ Health Perspect 2003;111)). Qualitative interviewing can elicit perceptions, experiences and aspirations; focus group discussions can explore normative influences and societal expectations; ethnographic observations can explore institutional processes (Patton, 2015 Sage). Qualitative evidence synthesis can bring together understandings from existing research on a topic area in order to understanding experiences, attitudes and behaviours form a range of settings (Garside, 2013; in Zeibland et al Oxford University Press). Participatory action methods can support knowledge mobilisation by including publics directly in research processes, design, data collection analysis and dissemination (Ungar et al Qualitative Social Work, 2015;14(5)). Stakeholder (and expert) interview studies can directly engage policymakers, the private and third sectors to understand barriers and facilitators to planned actions, and encourage co-production of knowledge (Ogilvie et al,

BMC Public Health 2009:9(1)).

What is the scientific importance of this area to the UK Environmental Research community?

Currently, NERC is not maximising the impacts from the research it funds for a variety of reasons: There are not enough environmental scientists with a deep enough understanding of the public involvement process and its practical application to their research. There is an urgent need to systematically address contemporary challenges to environmental sciences such as mistrust in science, and the disconnect between values and action, attitudes behaviour change, and between science, policy and practice. Moreover, natural scientists often need to consider humans as part of natural systems, and engaging with people as resource users and important sources of information (e.g. Hind J Mar Sci, 2015;72(2)). NERC scientists are increasingly engaged in interdisciplinary research teams and projects (e.g. as part of the GCRF agenda) to address this knowledge gap, but collaborations with disciplines that follow very different research agendas can introduce another level of knowledge translation challenges. A working knowledge of involvement and social science methods can help to overcome disciplinary boundaries, and lead to more successful and sustainable collaborations. Following the example of other science fields such as medicine, environmental sciences should actively harness theoretical and methodological approaches from the social and behavioural sciences to understand individual, social, economic and political contexts in which knowledge is produced, and acted upon. Qualitative methods provide rigorous research designs to explore and engage communities, industry and policymakers in systematic, scientific ways beyond public engagement activities, and have proven useful when applied to other disciplines such as public health. Bringing those methods and approaches into the environmental sciences beyond collaborative efforts with other disciplines will enable us to address current challenges most directly, efficiently accelerating impacts from NERC-funded science.

What is the UK's current capacity to deliver high quality training in this area?

UK research institutions have leading expertise in public involvement and its methodologies, and importantly, many UK researchers increasingly specialise in working at the intersection of disciplines and methodologies. For example, fruitful collaborations between social scientists and public health researchers have led to recognition of the need to harness transdisciplinary research capacity to develop novel approaches to behaviour change (Academy of Medical Sciences, 2016: Improving the Health of the Nation by 2040). Further cross-over with overlapping objectives has produced transdisciplinary fields such as ecological public health and planetary health, which emphasise the complex interactions between health and the environment (https://www.rockefellerfoundation.org/our-work/initiatives/planetary-health/). Such interdisciplinary experts are well placed to take on mentoring roles for fellowship schemes or provide short courses or skills workshops, which could be open to doctoral candidates or established scientists. This will also produce environmental science researchers well-positioned to meet the requirements of the increasingly common joint RC funding calls in the future. For example at the University of Exeter, the training priority was identified by a team of interdisciplinary researchers with the following expertise: European Centre for Environment and Human Health: Prof LE Fleming (epidemiology, environmental health), Dr C Guell (qualitative methods, knowledge exchange, behaviour change), Dr R Garside (systematic reviews, qualitative evidence synthesis), Dr K Maguire (Community engagement; patient and public involvement). Environment and Sustainability Institute: Dr R Turner (resource-use behaviour and decision-making, responses to environmental change). College of Life and Environmental Sciences: Prof K Brown (qualitative methods, public's understanding of environmental change).

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

N/A

What would be the impact of NERC investing in a CDT in this area at this time?

N/A
What would be the impact of NERC not investing in a CDT in this area at this time?
N/A

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

None

11. Forested Landscapes

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
A NERC CDT on forested landscapes Priority: to provide a doctoral cohort trained in the skills needed to protect, improve, expand, innovate, and research into forested landscapes at patch to forest scales. That is, a cohort trained in life and environmental sciences at scales above cell and whole organism plant physiology but below the typical scales of satellite Earth Observation. Although applicable to all forests, the focus should be on temperate systems most relevant to the UK supporting, provisioning, regulating, and cultural ecosystem services. Scope: we consider forested landscapes to be all landscapes significantly influenced by trees: large forests, agro-forestry mosaic landscapes, planned and unplanned woodland patches in town and country, as well as the urban green spaces, wasteland, and street trees that make up the urban forest. The ecological and socio-economic performance of these landscapes is dominated by the physiology of woody plants, and the ecology around woody plants. It is in understanding this eco/physiology and its application(s) to the real world that the most important skills gaps lie. Specific skills training: the UK has established research expertise in plant (especially crop) physiology, biogeochemical cycling, GIS, hydrology, climate and carbon, and has a strong leading position in emerging topics such as (meta) genomics and aerial robotics for remote sensing. The new CDT would (1) ensure the continuation of key sectoral skills and (2) bring emerging skills into the sector. Key sectoral skills to protect include: botanical genetics and taxonomy; forest biodiversity including taxonomy; biomechanics; and forest carbon, water, nutrient cycling, and praxis. New skills to bring into the sector include: epigenetics of long-lived organisms; multi-omics approaches; network biology; material science of wood including the bioeconomy of wood-derived products; and natural capital accounting.
Please evidence the training need in this area from business, policy and/or third sector users.
The societal benefits of UK trees are worth Â£1.9bn per year (Forestry Facts & Figures (FFF), Forestry Commission, 2016). Excluding flood benefits and health benefits other than air pollution mitigation, the total in-perpetuity value of UK woodlands is estimated to be Â£270bn (The Economic Benefits of Woodland, Woodland Trust and Europe Economics, 2015). Yet, timber is our sixth largest import: 1M tonnes of hardwoods alone are imported (Sylva Foundation, Our Forgotten Forests, 2011). The second-largest UK trade deficit in building materials in 2013 was in sawn wood (Â£683M). The overall 2013 trade deficit in wood-based materials hovers around Â£1bn over recent years (BIS statistics on building materials and components, May 2014). This is not because there is no UK resource: only 43% of the 3.16 million hectares of UK forest are independently certified as sustainably managed (FFF, op. cit.). A Defra report on Strategic Analysis of Capability and Capacity to undertake Tree Health Research and Evidence Activity in the UK (2013) identified three key deficiencies: (i) pest and pathogen biology and epidemiology; (ii) control and management; and (iii) adaptation and resilience in forests and forestry. Additionally, 74% of employers report a technical knowledge skills-gap in their employees and job applicants (Forestry Skills Action Plan, 2010). Climate-adaptive silviculture and servicing the growing bioeconomy are identified as key high-level gaps. The forest sector is changing, and needs doctoral-level skills more than ever to manage the change. The EU Standing Committee on Agricultural Research 4th foresight report 2015 stated that the future trend is to prepare the forestry sector for a multifunctional, better, use: energy, fuels and chemicals, plastics, construction, furniture, landscape, recreational activities and other ecosystem services□. Every aspect of

this change requires doctoral-level thought leadership to stand beside practitioner innovation within the sector.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

This submission results from discussions across the sector and includes the direct input of senior managers from: the Arboricultural Association; Birmingham City Council; the Forestry Commission; the Grown in Britain industry advocacy group; the Institute of Chartered Foresters (ICF); J & L Gibbons Landscape Architects; the Municipal Tree Officers Association; Transport for London; and the Woodland Trust. The input, therefore, comes from across the private, public and third sector constituencies within forestry and arboriculture. There is a clear appetite across the sector to become more involved in doctoral training. Many sectoral actors support CASE studentships and are partners in NERC Doctoral Training Partnerships (DTPs). However, this piecemeal approach results in patchy delivery of a trained workforce back into the sector at exactly the time when more concentrated skills-building is urgently needed. Several charitable organisations support fully-funded PhD studentships in forest topics, particularly the Scottish Forestry Trust and the Royal Forestry Society and often support jointly-funded studentships. Sector actors have a track record of research collaboration. The recent Â£7M Tree Health and Plant Biosecurity Initiative involved partnership between NERC, Defra the Forestry Commission, and other partners over three phases of funding. Private sector, governmental agencies, and NGOs have come together to provide Â£2M since 2013 for research into acute oak decline.

How will the proposed training meet the identified demand for these skills from end-users?

Training through leading-edge doctoral research projects introduces new skills into the sector, such as hyperspectral imaging, agent-based and graph-network modelling, multi-omics and bioinformatics, whilst building a cohort of doctoral researchers with generic skills in reading forested landscapes with scientific rigour. This will provide the sector with to meet the demands of change outlined above. The CDT should upskill researchers by a combination of generic and project-specific training. Generic training would be shared with other CDTs and DTPs wherever possible, and make use of the NERC-funded Advanced Training Short Courses, such as in the use of aerial robotics, next-generation sequencing, and soil science. Bespoke training elements inside the CDT would be co-designed with a broad range of sectoral stakeholders and focus on those technical skills especially prominent in forest research: forest ecology, innovative harvest techniques such as continuous cover forestry, and the value chain of wood in a circular economy, for instance. More broadly, the CDT would provide a training element involving educational outreach. Mentored working with groups of children of all ages would provide an explicit pull factor into the sector by helping young people (and their careers teachers!) to recognize the fascination of working in the forests. This outreach would be facilitated through well-established networks such as those of the ICF, forest schools, community forests, and the discipline-specific teachers networks (principally the Royal Geographical Society and the Royal Society of Biology). Doctoral researchers from the CDT who stay in academia will develop undergraduate modules and programmes including a stronger focus on temperate forests, and so help graduate skills be more suited to the sector in the medium and long term.

What is the scientific importance of this area to the UK Environmental Research community?

Forests are critical components of global carbon, nutrient and water cycles, influencing the thermal balance of Earth directly and indirectly, and are home to more than half of all known species. Forests deliver direct economic, environmental and social benefits, ranging from sustainable fuel and building materials, to the sense of well-being associated with a walk in the woods. A Forested Landscapes CDT would approach the study of forests in a systems-thinking multi- and inter-disciplinary perspective. The CDT would concentrate on higher-level skills and the transfer of knowledge and technology from disciplines that society values

highly such as medicine and economics to the sometimes Cinderella discipline of forest research. Rapid advances in sensor technology, made in the last decade, offer the opportunity to study forest dynamics across space and time with unprecedented resolution. Current state-of-the-art equipment can utilise many parts of the electromagnetic spectrum to provide information about landscape-scale temperature and canopy conductance (thermal infrared); leaf physiology (multispectral imaging) and canopy structure (passive radar using the Global Positioning System (GPS)). There has also been a revolution in omic technologies (i.e., genomic, transcriptomic, metabolomic technologies) over the past decade, opening the door to comprehensive species-level biodiversity audits. Using next generation RNA sequencing it is now possible to monitor the regulation of hundreds to thousands of metabolites in response to environmental stimuli such as elevated CO2. The UK university sector has existing expertise in all these areas and is bringing them to bear patchily to investigate the biotic and abiotic challenges to forests. Much of this omics expertise is currently dedicated to biomedical research, but there are significant opportunities for cross-over from biomedical research to forest research, particularly as high-throughput systems come on-stream

What is the UK's current capacity to deliver high quality training in this area?

There are currently no doctoral programmes in this area running under RCUK or the Leverhulme Trust or as UK-based EU ITNs, but there is ample research capacity in the NERC community and cognate research groups across the BBSRC and EPSRC communities. UCAS-listed undergraduate forestry and forest management degrees are delivered by the universities of Aberdeen, Bangor, Cumbria, and Highlands & Islands. NERC-remit universities providing doctoral training in forest science include Cambridge, Edinburgh, Oxford, and Sheffield. Urban Forestry is very poorly served by NERC-active PhD providers. Doctoral research provides a valuable route into the sector for graduates from cognate subjects across Biology, Environmental Sciences, and Geography. Current provision does not meet demand. The UKs capacity to deliver high quality training in temperate forest science has been very significantly enhanced by the foundation (in 2013) of the Birmingham Institute of Forest Research (BIFoR). The flagship BIFoR infrastructure is a Free-Air CO2 Enrichment (FACE) facility: the first whole-ecosystem FACE experiment for decadal exposure of a mature temperate forest to elevated CO2. In BIFoR FACE the trees are more than 160 years old and the forest soil is centuries older, providing a unique opportunity to fill critical gaps in the understanding of temperate forests. BIFoR FACE has been established via a Â£15m philanthropic gift; an equivalent University of Birmingham investment ensures base operation of the FACE facility to 2026. BIFoR FACE makes a CDT in this area particularly timely. BIFoR FACE is operated as a community facility; access is controlled by a committee that includes UK NERC-remit members from within and outside the University of Birmingham. BIFoR governance includes an Advisory Group formed from academic and industry stakeholders from the UK and beyond.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

One could accept all the arguments above for the essential importance of forests, and yet conclude that it is not necessary for there to be doctoral training focused specifically on forest research. Forests consist of living organisms, and as such are the concern of biology and BBSRC Doctoral Training Centres (DTCs). Very little engagement with the sector comes through this route. Alternatively, one could consider forests as terrestrial environments and study them within generic NERC DTPs. However, it is important to recognise the complexity of the issues involved in forest research, precisely because of the environmental, economic, and social issues surrounding forests. NERC has a track record of scientific training for complex rural and coastal systems but has yet to focus on UK forest resource. A Forested Landscapes CDT should focus centrally on expertise from the life sciences, environmental science, human and physical geography, while drawing on engineering & the physical sciences, Business Schools, and even Arts faculties, where

necessary. This confluence of research expertise is not possible through standard RCUK DTCs and urgently requires structuring through a dedicated CDT. The central place of environmental physics, chemistry, and biology in forest research places the topic firmly in the NERC remit.
What would be the impact of NERC investing in a CDT in this area at this time?
Humanity has always, and will always, need to understand forest. The NERC community provides leading intellectual engagement in tropical forest research but has not focused to the same extent on temperate forest research recently, even though carbon capture by temperate forests is the largest uncertainty in the global carbon budget (Le Quere et al., Earth Syst. Sci. Data, 7, 349-396, 2015). The decline of our level of skills in temperate forest science and management at least in the UK - is indicative of the low social value we currently attribute to the curation of one of our most precious ecosystems. The Forested Landscape CDT should include studies on how to value our landscape and enable public participation in environmental decision-making which, together with research into the environmental and ecological functioning, are vital aspects of re-shaping our view of, and valuing of, forests. A Forested Landscapes CDT will reinvigorate innovation in the sector by providing evidence on where environmental value lies in the UK bioeconomy value chain. This upskilling can then be deployed beyond the UK: in China, for instance, temperate forest utilisation in the biomass energy industry is rising currently at 19% per year, and by 2012 was producing 8GW of electricity per year (http://www.renewableenergyworld.com/ugc/articles/2014/07/for-a-green-future-an-overview-of-biomass-energy-in-china.html).
What would be the impact of NERC not investing in a CDT in this area at this time?
Inaction now will mean that the UK forest-sector will remain uncoordinated and uncompetitive in its doctoral training, much reducing its potential contribution to UK plc. The expected change of 5-13% of arable land to short-rotation coppice and miscanthus for biomass energy (Committee for Climate Change estimates, 2011) will not be accompanied by sufficient research into the impact on natural capital and ecosystem services. Utilisation of wood for high-value chemical feedstocks to replace fossil fuel sources will continue through other arms of RCUK and the chemical industry without the same depth of focus on environmental and biodiversity impacts, ecosystem services, and natural capital.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

None

12. Land Surface Science

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Many environmental challenges are multi-sector (e.g. the impact of land degradation and climate change on food production and floods and droughts) rather than single sector. The science required to meet these challenges is complex, requiring new approaches in data analysis and physically-based models. The emerging field of Land Surface Science (LSS) studies ecosystem dynamics and function, including their interactions with people and land use, combining aspects of meteorology, soil science, hydrology, plant physiology, with social science. LSS is therefore a powerful tool for tackling multi-disciplinary environmental and development challenges. Land Surface Models can be used to explore the science. The Joint UK Land Environment Simulator (JULES, jules.jchmr.org) was developed in the UK and is a world-leading model for climate-research used at research centres and universities across the UK and internationally. Run by the Centre for Ecology & Hydrology (CEH) JULES simulates the interactions between land and atmosphere at local and regional scales. JULES acts as the land-surface component of both the NERCs Earth Modelling Strategy and the Met Offices Unified Model (which is central to climate and weather prediction). Training would produce environmental scientists with the ability to both use and further develop complex Land Surface Models such as JULES. Specifically students would receive training in the following: - The environmental science areas included within JULES. - How this science is implemented within JULES, including model structure, coding practices and the different options for running the model. - Principles of numerical methods, including discretising differential equations. - The data used to evaluate the model and issues of performance and metrics. - The philosophy underlying the model and the associated inherent uncertainty. - How to deliver major multi-sector issues using the JULES model.
Please evidence the training need in this area from business, policy and/or third sector users.
It is established (NERC Skills Gaps Analysis) that there is a lack of skills in the UK in the use of models and in particular a model as (necessarily) complex as JULES. As a result of increasing intricacy of multi-sector environmental challenges, there is a demand for environmental scientists trained in complex modelling skills to enable accurate prediction of future changes and risks. This will enable government, industry and society to mitigate and adapt successfully. A particular example is the future proofing of the MET Office climate prediction suite. JULES is currently used by the MET Office for a variety of different purposes including: - Development in understanding of land atmosphere interactions. - Investigation of the impact of land surface characteristics on the prediction of weather and climate. - Development in understanding of land processes that contribute towards climate change e.g. the terrestrial carbon cycle. - Investigation of the impacts of climate change on the land surface. In addition JULES has application in hazards and disaster risk reduction through the prediction of hazardous weather, flooding and urban environmental risk. The need to build resilience and enhance preparedness through increased understanding of disaster risk was highlighted by the UN Sendai framework. JULES is also a central part of the UKs climate and Earth system model informing climate policy by contributing to the CMIP and IPCC Assessment reports. There is also great potential for JULES to form a key part in the achievement of the UN Sustainable Development Goals through applications in food and water security, land management and ecosystem resilience. It is vital for JULES to remain at the forefront of Land Surface modelling capability. Requiring continued development and innovation to ensure maintenance of accurate environmental and climate

forecasts for a wide variety of users.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
There is increased funding available to work in the developing world both through the Global Challenges Research Fund and the World Bank. The JULES model is an appropriate tool for delivering UN Sustainable Development Goals for example, and training has potential to leverage funding from these sources.
How will the proposed training meet the identified demand for these skills from end-users?
The proposed training would enhance technical support capabilities of the JULES user group. Issues such as the development of new code followed by processing, testing and reviewing would be addressed. There would also be more opportunities for operational support and development plus increased community engagement and facilitation. This would lead to an increase in new users from both academia and commercial backgrounds and further growth of the JULES community.
What is the scientific importance of this area to the UK Environmental Research community?
Currently JULES serves to link the research of UK and international universities, government laboratories and research organisations. There is a need to grow the next generation of environmentally focused modellers, not only capable of running models but with the skill sets required to develop them. This would enable the UK to build capacity to meet an increasing demand for highly accurate climate change and environmental risk predictions. Such growth would build on the existing JULES community linking the Met Office, CEH and UK and international universities, building collaboration between scientists working in diverse areas. A greater number of researchers using JULES will also help with quality control and enable benchmarking tests to be carried out across more users.
What is the UK's current capacity to deliver high quality training in this area?
There is currently a central hub of core JULES users numbering 10 based at CEH and the MET Office with a further 100 spread across UK universities. Demand for training and support in the use of JULES by the academic community and outside is growing at a greater rate than there are individuals to support this expansion. CDT students would support local users and encourage new ones significantly adding to the capacity for the JULES community and its capability for growth.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
Delivery of training through a CDT would enable a collaborative approach. Students from different environmental backgrounds would be brought together and encouraged to work across disciplines. As the environmental challenges to be faced are multi-sector, a cross disciplinary approach is critical for the maximisation of innovation and to enhance cross-fertilisation of ideas. Funding for training would support the development of a specialist training programme, combatting the current shortfall in training capacity. The CDT set-up would also be able to take full advantage of the existing investment and infrastructure represented by the JULES network; building on existing links between research organisations and universities. Collaborations between the Met Office, Centre for Ecology & Hydrology and universities will be enhanced. Links with the business sector would also be encouraged through the opportunity for CASE studentships.
What would be the impact of NERC investing in a CDT in this area at this time?
JULES is a world leading model for environmental research, delivering predictions with great accuracy and precision. These predictions inform decision makers and underlie UK environmental policy.
What would be the impact of NERC not investing in a CDT in this area at this time?
Failure to provide adequate investment in the training of future users and champions would

risk JULES losing its current status.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

None

13. Mineral Resources

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Mineral resources underpin all manufacturing and infrastructure development in the UK. In volume/tonnage terms minerals and mineral products constitute the largest material flow in the (UK) economy, accounting for about 16% of the total, according to the draft UK minerals strategy www.mineralproducts.org/documents/MPA_UK_Minerals_Strategy.pdf. Almost all specialist metals and other raw materials are imported, requiring expertise and entrepreneurship in a global environment. The minerals industry is a clear destination for UK researchers post-PhD, and as such a CDT represents an opportunity to improve the scientific, technical and transferable skill components of a PhD programme by: 1) Teaching transferable skills and cross-disciplinary aspects with a clear problem-based focus (e.g. mitigation of environmental impacts, valuation of natural capital, responsible management of natural resources, social science, communication). 2) Dedicated and specialised provision of technical skills training in key areas identified by NERCs Strategy, Most Wanted□, and industry: sustainable development, mineralogy and petrography, environmental management, geochemistry, fieldwork, remote sensing, geostatistics, GIS software, laboratory and analytical skills, valuation of natural capital, resource economics, environmental impact assessment, hydrology, contaminated land assessment, carbon accounting, data analytics. 2) Delivering training by academics and industrial partners. 3) Allowing for multiple supervisors from a wider network defined by expertise not location. 4) Representing a single contact point where industry can identify the best partners, and ensure projects, supervisors, technical facilities and students are all properly matched. A Mineral Resources CDT would improve the student experience by providing direct access for students to industrial peers and professional environments, offering dedicated training in the appropriate skills and application to relevant problems
Please evidence the training need in this area from business, policy and/or third sector users.
The UK is a vital part of the mineral resources industry, and is home to the many of the world's largest mining companies. UK researchers play a key role within the technical, strategic and managerial directions of these multinational companies, and have strong links with UK academia in support of both research and training of postgraduates (and undergraduates). The UKs commitment to the UN Strategic Development Goals (SDGs) will be significantly boosted by a program through which UK researchers can be trained for the mineral resources industry. The supply of raw materials underpins the following SDGs: Affordable & Clean Energy; Industry, Innovation and Infrastructure; and Sustainable Cities and Communities. Progress towards these SDGs is only meaningful if the resource sector can continue to improve in Responsible Consumption and Production, and further reduce their impacts on climate and ecosystems. Delivering researchers (and research) to deliver on these SDGs is best met through NERC and UK academia continuing to supply highly skilled, multi-disciplinary scientists and engineers to industry. NERC have funded mineral resources-oriented doctoral training courses on three occasions (NE/M006603/1, NE/N019040/1, NE/P020402/1). These have been led and delivered by a blend of researchers, academics and industry professionals. The success of these courses demonstrates that the mineral resources community can deliver excellent training; the popularity of the courses demonstrates a demand for industry-facing skills in the UK PhD cohort. The delivery of these courses on a number of occasions demonstrates their value to both students and industrial partners.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
The UK mineral resources community has shared spaces for academics, professionals and students. Professional bodies such as the MDSG (Mineral Deposits Studies Group) of The Geological Society, IOM3 (Institute of Materials, Minerals and Mining) and Applied Mineralogy Group of the Mineralogical Society, already reflect sharing of research and networks. The academic community have had recent successes with NERC, through a strategic program (NERC SOS, www.bgs.ac.uk/sosminerals) and highlight topics. There is a significant body of curiosity-driven research active in the UK. The SOS program hosts 17 PhD students (funded at 50% by NERC, the remainder by matched funding). The program has 50 industrial partners, reflecting a significant degree of engagement. Mineral resources-oriented doctoral training courses included trainers from industry. In the feedback to the most recent application (NE/P020402/1), reviewers said The staff have a strong track record in this area with some outstanding field geologists from Industry, Academia and the Public Sector The contribution of a leading geological consultant at "no cost" is welcomed. A unique course with significant demand. Industry professionals recognise the value in training students with appropriate skills, and would engage with a CDT. A number of UK research groups have received significant investment from the minerals industry to support research and particularly PhD projects. For example, the LODE group at Imperial College / Natural History Museum have significant investment and engagement from industrial partners (http://www.imperial.ac.uk/earth-science/research/research-groups/lode/); the University of Bristol has an ongoing collaboration with BHP Billiton (http://bristolpcd.org) that has led to significant investment in PhD studentships. Such partnerships demonstrate the ties between academia and industry in the UK; a NERC CDT could leverage these relationships to boost training, research and industrial engagement.
How will the proposed training meet the identified demand for these skills from end-users?
The most widely cited technical skills that the minerals industry desires in graduates are: field skills, software skills, and appreciation of data quality and analytical methodology. A Minerals CDT can directly address these through a national cohort being trained through a series of targeted training courses (field training in UK or international areas of classic economic geology; software training courses; exposure and access to a complete range of analytical techniques; industrial internships). There is a growth in demand for skills that underpin sustainable development and corporate social responsibility within the resources industry. There is an opportunity for a CDT to deliver transferable and/or multi-disciplinary technical skills that are focused on these particular agendas. As demonstrated above, a key tenet within the community in recent years is that academia trains students WITH industry, rather than FOR industry. Existing partnerships and platforms offer the opportunity to deliver training that matches industrial needs, as they will be (and have been) actively involved in the planning and delivery of that training, rather than passive agents.
What is the scientific importance of this area to the UK Environmental Research community?
This directly aligns and addresses NERC Strategic priority of Benefiting from Natural Resources. The UK has a thriving community of mineral resources research: the active NERC SOS programme involves 21 research organisations in the UK, delivering curiosity-driven science aimed at improving the sustainable use of natural resources. The UK research community delivers research aimed at understanding the fundamental processes that form mineral resources, innovative methods for resource exploration and discovery, developing environmentally-benign methods of extracting and processing them, and minimising the negative environmental and social impacts that have historically been caused by mining.
What is the UK's current capacity to deliver high quality training in this area?
The current NERC strategic program SOS Minerals hosts 17 PhD students who receive

cohort-level training through residential summer schools. Additional training courses run by members of the resources community in the UK include advanced training short courses (NE/M006603/1, NE/N019040/1, NE/P020402/1). There is both a demand from students and a capacity to deliver excellent training from both academia and industry. There are large (>3 researchers) mineral resources research groups at the Natural History Museum, Camborne School of Mines, the British Geological Survey, and the Universities of Leicester, Cardiff, Bristol and Southampton. There are smaller groups and individuals at a larger number of UK institutions. A CDT platform that can take advantage of this distribution of expertise and facilities in an appropriate fashion can produce a world-class collaborative centre for training and research.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

The UK has a healthy community of academics, researchers, professionals and students; however, it is widely distributed, and as such lacks a critical mass within the (largely regional) NERC DTPs. Skills training for mineral resources is limited to short courses, including those delivered by learned societies and industry professionals. PhD students within the Camborne School of Mines (University of Exeter) have access to on-site and blended learning MSc-level courses in mining and resources. Within other DTPs training is generic. A CDT could be more focused, yet still retain a blend of multi-disciplinary science, technical and transferable skills. A CDT with a thematic focus rather than a geographical basis would allow the community to support PhD students and deliver excellent training through a collaborative platform. Recent grant successes through Highlight Topics and the SOS program demonstrate the community's willingness to work together. SOS has a PhD cohort that receive training through a Summer School program. The positive feedback received for these events so far has shown the value in dedicated training for more focused PhD researchers, and indicate one mechanism by which nationally distributed students might be successfully trained as a cohort. The current PhD community within UK mineral resources is strongly underpinned by the SOS cohort; however, they are all expected to have completed their PhDs within 2-3 years. There is at present no mechanism for replacing the students or the underpinning funding. Although some universities have been successful at getting PhDs funded directly by industry, the students within these small cohorts are only able to (formally) work with a limited group of academics. A CDT would allow the wider community to better support industry-funded students with access to expertise, facilities and training; universities with strong industry financial support would be able to leverage additional research through matched funding.

What would be the impact of NERC investing in a CDT in this area at this time?

A CDT in mineral resources would allow the UK to maintain a global reputation in delivering excellent research and training highly skilled scientists to professional and academic roles. It would provide training for researchers that would support delivering on the needs of the 21st century, with an efficient and environmentally sustainable supply of natural resources. A CDT would provide the community with a reliable stream of PhD researchers, and allow us to deliver training that is closely tailored to both their research and career ambitions. The training could also be offered to early career industry professionals as CPD to further enhance the UKs position as a knowledge hub within the minerals industry.

What would be the impact of NERC not investing in a CDT in this area at this time?

The SOS cohort of PhD students is due to complete in ~2019. A failure to replace these PhD students would mean that community cannot capitalise on training schemes put into place to support those students; the community would see a significant drop in both PhD students and in subsequent years, early career researchers. Without a reliable source of PhD-level scientists to recruit from, we can expect a decline in the engagement of industry with the UK research community, particularly in periods where markets do not favour the mining industry and direct funding of research becomes difficult.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

14. Geoscience for a Smart Mining Cycle

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
GEOSCIENCE FOR A SMART MINING CYCLE: exploration, resource evaluation, mining processing, remediation, and social licence to operate. The drive to mitigate climate change through low carbon economies and renewable energy technologies will majorly increase the need to discover, mine and extract critical metals for future energy infrastructure. Mineral extraction requires enormous amounts of energy: crushing ore alone uses ~4% of global energy [1], and a study for the Australian government projected their mining sectors energy use to increase by 250-300% between 2010 and 2030 [1]. Increasing the sustainability of the mining cycle will be critical to achieving global carbon targets, while supporting national growth, especially within Official Development Assistance recipient countries, and ensuring the viability of mining companies. This challenge will require a holistic geoscience-based Smart mining cycle approach, including exploration, mining, processing and remediation, involving interdisciplinary research (resource evaluation, applied mineralogy, mining engineering, chemical engineering and environmental management). Students from geology, environmental science and engineering backgrounds will require training in different aspects of the mining cycle from exploration through to closure and rehabilitation. This could include: advanced techniques for exploration such as mineral prospectively analysis and analysis of geophysical and geochemical exploration data, including core analysis, advanced software for resource estimation and mine planning; advanced mineralogy instrumentation and techniques; geotechnical engineering applied to mining and waste storage; mineral processing; and techniques for environmental rehabilitation and monitoring. Also needed is a better interdisciplinary understanding of the rights of local communities that are essential for the minerals industry to obtain the social license to operate. [1] Australian Energy Projections to 2029
Please evidence the training need in this area from business, policy and/or third sector users.
Evidence of the training need is outlined by the European Commission The raw materials industries are facing increasing skills shortage. This challenge needs to be addressed through communication and partnerships between civic society, public authorities, universities, research organisations, and industry. The Commission supports the development of new high skills on engineering, material science, geology or earth observation. [1] Increasing demand and projected decreases in metal grades will further tighten business margins, necessitating highly skilled, interdisciplinary scientists and engineers, who can work collaboratively to apply the best technologies at the right time. Universities have historically trained geologists, environmental scientists, and mining, mineral processing and chemical engineers separately. Any shared training tends to come only at introductory undergraduate level before students specialise. Some larger mining companies (e.g. Anglo American, Rio Tinto, etc) provide short (2-3 months) periods of internship training for BSc and MSc-level students, with a view towards recruitment, but there is no equivalent at PhD level. All of the above groups are essential to a modern mining operation and there is an unmet need to provide comprehensive research-level training whereby students are exposed to a carefully designed combination of short courses covering geological, environmental and engineering issues that take place over 3-4 years alongside their PhD research. The training currently offered to PhD students in the minerals sector by geographically distributed DTPs is dependent on the local partners and their interests and expertise, rather than specifically involving those institutions with the strongest

track record, and tends not to be co-ordinated and focussed towards a specific area that meets the needs of industry. 1 European Commission website: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/skills-education_en

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

The UK provides the global headquarters for many of the world's largest mining companies listed on the FTSE100 stock exchange and mid-cap/junior companies listed on the AIM exchange. Until now, individual companies have provided ad hoc training or internship opportunities for individual PhD students carrying out research that they support, or have chosen to provide more general partnership support within a geographical DTP such as GW4+. However, there has been no collective and interdisciplinary approach to PhD training specifically aimed at improving efficiencies across the whole of the mining cycle, which groups of companies could potentially buy into and support in a collective manner. The minerals industry has highlighted the need for applied interdisciplinary training and team-based problem solving at PhD level and would support it financially if it was open and available to all partners, rather than each company having to provide it themselves. Collective support by the mining industry for clearly identified research areas or themes involving multiple academic partners have a long history in both Australia (through AMIRA projects) and Canada (e.g. the current Footprints of Ore Systems funded by NSERC and the Canada Mining Innovation Council). By adopting a consortium approach among the academic partners, companies would get access to the most suitable research teams and potentially across multiple rather than single institutions if shared supervision was written in as a condition of each PhD award. Similar models have already been trialled within NERCs Oil and Gas CDT and for the 20 strong PhD student cohort funded under NERCs Security of Supply for Minerals research programme and have been shown to be both popular and successful with students and partner companies.

How will the proposed training meet the identified demand for these skills from end-users?

Students from geology, environmental science and engineering backgrounds will receive training in different aspects of the mining cycle from exploration through mining to closure and rehabilitation. This could include: Techniques for global resource evaluation; regional prospectively analysis (largely GIS based); handling of geophysical and geochemical exploration data; advanced software for mine-scale resource estimation and mine planning; advanced mineralogy instrumentation and techniques applied to mining and metallurgy; geotechnical engineering applied to mining and waste storage; modelling and experimental mineral processing; and techniques for environmental rehabilitation and monitoring. Students undertaking this training alongside their individual research topics would emerge with both subject-specific and interdisciplinary skills covering major aspects of the minerals industry. They would have experience of working with industry and with problem solving and presenting in focussed interdisciplinary teams. These skills are highly valuable and not widespread among current PhD graduates. They are also not developed by the current suite of geographically focussed DTPs. An initiative from NERC to develop a central training hub and a network of academic partners would draw significant support from industry, as evidenced by the buy in from over 50 different industrial partners that accompanied the SoS Minerals programme.

What is the scientific importance of this area to the UK Environmental Research community?

Global resource evaluation, commonly using the techniques of systems analysis, is a trend-setting research agenda, which is largely led at present by overseas organisations such as the Institute for Sustainable Futures at the University of Technology in Sydney and the Centre for Sustainable Investment and the Earth Institute of Columbia University. A global scientific view of resource distribution is increasingly important in times of political uncertainty. The most basic information required for planning and directing research into

these resources is a global inventory of these metals, which can be expressed through the concepts of peak metals/minerals. However, there are very different estimates for total resources and the timing of peak metals/minerals. One of the major variables in resource estimation is the distribution of natural resources between high and low grades of metal. There are opportunities to improve confidence in our global mineral resource estimates through more realistic tonnage-grade models, and through geochemically based approaches to resource prediction. These are applied science questions of major importance to the UK geoscience community in directing its research. There are several accessible sites for critical metal research allowing the investigation of a range of fundamental petrologic problems in the field and the laboratory. There is considerable potential for new ore deposits to be discovered in these intrusions, as evidenced by the recent discovery of a large new PGE deposit in the Bushveld, down dip of existing mines. Critical metals research also bears on the formation of the earth. For example, the concentration of global PGE resources in the Bushveld Complex may be due to tapping of mantle domains that contain a relatively high component of poorly dissolved late veneer. If true, this has implications for earth accretion and mantle convection.

What is the UK's current capacity to deliver high quality training in this area?

The UK is home to a number of universities with active research programmes devoted to minerals and mining. Many of these are lead partners in NERCs £12m SoS Minerals programme (Cardiff, Leicester, St Andrews, Aberdeen, Exeter, Southampton, Leeds) or in the recently approved £3m FAMOS highlight topic (Imperial, Natural History Museum, Bristol, Cardiff, Leicester and Open University). Institutions like Exeter, Imperial and Leeds are world-renowned centres for mining engineering and minerals processing and Cardiff, Nottingham and Strathclyde are key centres for the geo-environmental engineering needed for reclamation and remediation of former mining sites. There is ample capacity to assemble and design a consortium to cover the whole mining cycle and to meet the training aims of the proposed CDT. Critical metals occur in a range of geological formations, but amongst the most prospective are layered intrusions. They are relatively common, with > 400 bodies identified so far. The Bushveld Complex of South Africa is the best-known example, covering an area equivalent to Switzerland and occupying a quarter of the thickness of the continental crust. Critical metre-thick mineralized layers can be traced for hundreds of kilometres around its circumference. The complex hosts the world's largest and most diverse mineral deposits, including 80% of the world's platinum and 60% of the world's chrome and vanadium, in addition to other rare earth metals and the bulk of global andalusite resources. Layered intrusions and their ore deposits are ideal natural laboratories to train a new generation of UK applied geoscientists focussed on developing the Smart Mining cycle.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

A major impediment to UK research in, and development of, the minerals sector is poor communication between private and public sectors. The synergy that boosts research and industrial performance in Australia and Canada is largely absent in the UK. A major benefit of the CDT model will be the facilitation of improved interaction between academia and industry. CDTs cater for sector rather than individual company needs, deal with several commodities, and can cover the full value chain of exploration, mining, beneficiation and closure/remediation. CDTs can facilitate joint academic-industry planning of research projects, joint workshops on mine sites, and sabbaticals for company geologists and engineers in universities, and academics in companies. CDTs can develop novel teaching methods comprising a combination of field, laboratory, and web-based courses, and team-based problem solving. CDTs benefit from access to cutting-edge analytical facilities in laboratories in several universities, allowing new approaches in ore geology modelling. CDTs allow adaption of discoveries and techniques developed during fundamental academic research to the minerals industry including the application of state-of-the-art

geophysical methods such as seismic focusing and electrokinetic coupling to the exploration for deeply buried ore deposits, and X-ray fluorescence microscopy and 3D tomography to locate and identify phases hosting valuable ore components.

What would be the impact of NERC investing in a CDT in this area at this time?

By investing now CDTs could represent the UK response to the coming crises in critical metal supply. Successful exploration, mining and beneficiation critically depends on professionals with an increasingly varied range of skills, taught by global leaders in the field. The UK faces heightened competition for key natural resources in a global environment of increasing demand and decreasing access. Many key supplier countries of critical metals face significant political and societal insecurities, and the capacity and willingness of others to provide secure supplies to the UK in the future is uncertain. The ambitious 20-20-20 energy and climate targets of the EU[1] will impact on metal supplies globally. The fuel cells, photovoltaic cells and wind turbines required for a transition to a low carbon society will trigger a >100% increase in demand for many key metals over the next decades[2]. To meet this potentially dramatic future supply shortage, the UK needs to make better use of its internal resources, not only through better recycling and substitution, but also through improved efficiency in mineral exploration, mining and sustainability. In the case of Europe, potential strategies are outlined within the Raw Materials Initiative Meeting our Critical Needs for Jobs and Growth in Europe[3] and the European Technology Platform on Sustainable Mineral Resources [4] 1 European Commission website: http://ec.europa.eu/clima/policies/brief/eu/package_en.htm 2 Vidal O, Goffe B, Arndt N (2013) Metals for a low-carbon society. Nature Geoscience 6, 894-896 3 Brussels, COM(2008) 699: Communication From The Commission To The European Parliament And The Council The Raw Materials Initiative Meeting Our Critical Needs For Growth And Jobs In Europe. http://www.euromines.org/ who_is_downloads/raw_materials_initiative.pdf. 4 European Technology Platform on Sustainable Mineral Resources http://www.etpsmr.org/index.php?option=com_content& view=article&id=1&Itemid=2

What would be the impact of NERC not investing in a CDT in this area at this time?

The capacity to assess the global resource base for critical metals is of high importance to the UK. The best understanding of ore forming processes, geometallurgical and mineral processing options and best practice in mine closure and remediation would allow the UK to shape forward looking technology development in mining, and foreign and resource policy and to produce the next generation of leaders in these fields. Failure to do so would effectively hand this leadership role to foreign competitors. In the near term, the cohort of PhD students linked to the current NERC SoS Minerals programme is due to complete in ~2019. A failure to replace these PhD students would mean that the UK research community cannot capitalise and potentially expand the bespoke training schemes that have been developed by the project partners to train and develop these students. Without a reliable source of PhD-level scientists from which to recruit, the UK minerals research community can expect a decline in the engagement of industry with the UK research community, particularly in cyclical periods where metal prices are depressed and direct funding of research is very challenging.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

A CDT in GEOSCIENCE FOR A SMART MINING CYCLE will create truly interdisciplinary cohorts. Within Cardiff University alone we could draw upon expertise from our University Research Institutes in Data Innovation; Energy Systems; Sustainable Places; and Water, and our Schools of Bioscience; Chemistry; Earth and Ocean Sciences; Engineering; Law and Politics; Geography and Planning; and Physics and Astronomy.

15. Aquaculture

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
The recently announced Aquaculture Growth to 2030 strategy has suggested production targets potentially contributing a turnover value of £3.6 billion to the UK economy and supporting up to 18,000 jobs. The global market opportunity for aquaculture is not simply for increased production but also for UK based supply chain companies to capture value for the provision of equipment and services such as veterinary and diagnostic services, engineering, equipment, software, biotechnology, environmental management services and products and academic knowledge The UK aquaculture industry is reliant on the sustainable utilisation of the ecosystem services in which the industry is based. In order to ensure its continued economic and environmental sustainability it is crucial that there is a clear understanding within the industry and its regulators of the interaction between the industry and the environment. As such, a work force skilled in environmental science, modelling and environmental management is key to the future aspirations for the development of this industry. The students would receive broad training in a range of marine and aquatic sciences, biogeochemistry, environmental modelling, and socio-environmental interactions.
Please evidence the training need in this area from business, policy and/or third sector users.
The Scottish industry has recently completed the production of a road map for the development of the industry up until 2030. Within this document the industry has articulated the desire to dramatically increase production by 2030. To do this the industry has identified that skills development is a key component of this growth and a primary action for the delivery of the roadmap for growth.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
The growth strategy for 2030 was developed by the industry and as such the development of NERC training in line with this industry strategy would offer significant opportunity for industry partnership. In addition, there is a common understanding for the need of evidence based management and as such there is a clear framework for engagement with policy makers, and regulators. Within the aquaculture industry there is a proven track record of co investment in research innovation and education.
How will the proposed training meet the identified demand for these skills from end-users?
The 2030 aquaculture report identifies an industry demand to develop globally-respected executive education provision in the food and drink sector, including aquaculture not only developing its own cohort of skilled industry leaders but attracting people from all over the world. It is clear that there is a need for professionally qualified managers who understand the complex interactions between the environment and the aquaculture industry.
What is the scientific importance of this area to the UK Environmental Research community?
Globally aquaculture has surpassed capture fisheries in the provision of food to the world population. This is a step change in our relationship with the oceans, and has major implications for global food security. The rapid expansion of the industry in the last 50 years has resulted in a range of environmental issues both globally and in the UK and also an understanding that good environmental status is crucial to the economic and environmental sustainability of this industry. To address these environmental issues and support both the

global and UK industries requires a broad spectrum of science from underpinning blue skies in areas such as metabolomics, environmental DNA and population ecology through to translational science. As such, aquaculture is of broad interest to a wide range of the UK research community. This is evidenced by the large response to the two recent NERC/BBSRC aquaculture calls.
What is the UK's current capacity to deliver high quality training in this area?
The UK currently delivers a number of high quality aquaculture PhDs, masters and undergraduate qualifications through its University sector. However, these are delivered in a piecemeal basis and lack a coherent strategy for specifically meeting industry and the regulators requirements. As a result the UK considerable and world leading academic capacity in this area is not delivering to its full potential for the next generation of industrial leaders.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
The growth of the aquaculture industry globally and in the UK requires a highly trained professional level work force to ensure its long term economic and environmental sustainability. To develop such a work force to ensure that the UK remains at the forefront of industry innovation both in the UK and abroad requires a coherent training program at the managerial level to ensure effective and consistent integration with industry regulators and policy makers. A NERC CDT in aquaculture environment interactions would provide this coherent platform and allow NERC to capture the world leading academic excellence in aquaculture science that exists within the UK and transfer it to the next generation of environmental scientists.
What would be the impact of NERC investing in a CDT in this area at this time?
As previously mentioned the UK industry is poised for a rapid expansion, and globally the aquaculture industry is the fastest growing food production sector. This expansion over the next 5-10 years will lead to substantial environmental challenges which the industry and policy makers will need to effectively manage if the industry is to grow. The investment by NERC would be ideally timed to meet the growing demands of the UK and global industry would ensure that NERC science is embedded within this sector which is crucial to the national economy and global food security
What would be the impact of NERC not investing in a CDT in this area at this time?
Fail to invest by NERC would have a number of very deleterious impacts. Firstly, it would limit the expansion of the industry within the UK. The 2030 targets suggest an economic value of £3.6Bn annually. However, this expansion will be blocked if the industry and regulators cannot ensue the sustainability of the industry to a wider group of stakeholders. Without the level of effective environmental management which the CDT would help to ensure the growth of the industry will be effectively limited by a lack of stakeholder trust and ultimately a lack of social licence.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

16. The application of Geo- and Environmental Sciences as Society moves towards a Low Carbon Economy

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
The ongoing development of a comprehensive strategy to meet 21st century energy needs in a sustainable manner, as well as the continuing demand for oil & gas for fuel, manufacturing of plastics, in agricultural feed & fertilisers & for medicines, requires future scientists to be able to evaluate & combine concepts & data from a range of STEM disciplines in geo- and environmental science, engineering & statistics. Technical expertise in one area must be tempered with an understanding of the challenge between energy supply & climate impact. There is a need for technical expertise to inform the competing agendas of environmental impact & sustainability of operations to ensure science is balanced & fair, to engage & communicate to all stakeholders and to examine whether there a social licence to operate exists or not. It is important for future practitioners to be able to collate, digest & analyse large data-sets from a variety of sources, gathered in different ways, and to communicate the relative importance of different bodies of evidence to a range of audiences; the general public, politicians, and academic or industry professionals. Greater in-depth research & expertise in areas such as Carbon Capture & Storage, Decommissioning, Enhanced Oil Recovery, Environmental Monitoring of Unconventional Resources, Improved Oil Recovery & Characterisation of Reservoirs & Saline Aquifers are required. Industry sponsoring partners recommend a focus on field work to ensure that future practitioners have an understanding of a key but neglected element of importance to operating in the oil & gas space. Quantitative skills for geo- and environmental scientists are a vital enhancement to traditional research skills. Both areas are identified in NERCs Training Strategy as key skills for the environmental scientists of the future. It is the rounded, deep knowledge of environmental, geological, operational & analytical aspects which is so highly prized by industry & policymakers.
Please evidence the training need in this area from business, policy and/or third sector users.
Policy makers, regulators, industry and society in general all have different needs in their involvement with the process of producing heat, light, energy and the multiple by-products of oil and gas. As we seek to make the most of natural resources in an environmentally responsible and managed way, more individuals with a range of skills and experience and the understanding of how to work in collaboration with different disciplines and to sometimes competing agendas will be required. Oil prices are cyclical with a profound effect on industry decision-making e.g. accelerating or decreasing the speed of decommissioning or the appetite for exploration and it is vital that research and training provides a flexible workforce with the skills necessary to respond quickly to changes in global economies and operating conditions. Despite the downturn in the global oil price, new companies have joined the Oil & Gas CDT sponsorship partnership, both with finance and in kind support, demonstrating the value they see from developing a portfolio of skills and experience for the well-being of related technical disciplines and expertise in their future work force. Industry skills shortages were the subject of an FT article by their Energy Editor, Andrew Ward on 28/10/16. In its most recent licence round, the Oil & Gas Authority (OGA) also allocated 25 points to sponsorship of the CDT, demonstrating the much higher return they place on this than the acquisition of 2D seismic which costs 10 times as much but only carries 20 points. The Oil & Gas UK (OGUK) annual appraisal of the industry Business Outlook 2017 identifies the potential of new basins in the UK Continental Shelf and West of Shetland following industrys

implementation of cost efficiencies and the insecurity of the UKs gas storage and LNG supply capabilities. It also highlights the importance of exporting supply chain knowledge, especially in decommissioning, an area where the UK has the opportunity to excel.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

The CDT in Oil & Gas successfully leveraged @£7M over 4 cohorts from the 17 UK HEIs involved in the partnership and currently has @£1.6M committed industry funding for the training program with the prospect of a further £0.5M until 2021. For the price of sponsoring a single research project at one university, companies gain access to a portfolio of research across UK academia as well as opportunities to influence both research direction and the training curriculum to address their current and future skills needs. Sponsoring companies range from multi-nationals (BP, ConocoPhillips, OMV, Shell, Statoil, Total) to smaller companies (Cairn Energy, Maersk, PremierOil, Verus Petroleum, Woodside Energy) as well as in kind support from the likes of Schlumberger WesternGeco, PGS, Spectrum, Nautilus and AGR Tracs). Many companies provide support in kind through the provision of project data and acquisition trips, supervision, software applications, staff time & teaching materials for training courses. The implementation of a Young Professional Mentoring scheme linking PhD students with early career industry/regulatory professionals extends the skills network and knowledge exchange between academia and research users. The OGAs allocation of licensing round points to financial support of the CDT shows the value it places on this pan-UK, cross-disciplinary research & training model. The Decom North Sea Executive contributes regularly to the CDTs training program and wider involvement of the decommissioning industry's professional body is envisaged to address the specific training needs of that sector. The OGUKs Environment 2016 report sets out the increased challenge of environmental risks inherent in continuing production from mature basins e.g. produced water or re-scoping them for other storage uses. Enhanced environmental and commercial benefits are gained when discipline cross-over becomes the norm resulting in a holistic approach to decarbonising the UK economy.

How will the proposed training meet the identified demand for these skills from end-users?

The training program curriculum will be drawn up in consultation with end-users via a representative committee meeting at least twice annually. Training will be provided on a residential basis incorporating class teaching, practical group exercises and mandatory fieldwork to give students the experience of applying research to real-life challenges in the sector. Students will work in multi-disciplinary groups and have opportunities to discuss their research both with one another and with the range of training providers from industry, government and academia. Partner institutions will commit up-front to providing a proportionate number of days to the training program and courses will be held in different UK locations to widen further the students network and experience of other work environments. BEIS Industrial Strategy singles out the delivery of affordable and sustainable energy and clean growth to secure the industrial opportunities for the UK economy of energy innovation. Bringing larger groups of previously competing academic and industry partners together at the early stage of research careers harnesses synergies and builds mutual trust to pool resources and co-operate in the future. Partners contribute their recognised areas of expertise, including specialist niche skills which can be disseminated more widely as a result. The existing Oil & Gas CDT network is constantly expanding and has a track record in the successful delivery of courses in geo- and life sciences, economics and communications all of which encourage the development of new applications for ongoing research. The Industrial Strategy also promotes the use of Remote and Autonomous Vehicles for Decommissioning and other themes relevant to environmental monitoring of the oil and gas activities.

What is the scientific importance of this area to the UK Environmental Research community?

The UNs 17 Sustainable Development Goals, and the BEIS and OGUK documents already mentioned all confirm the continued need to use the natural resources of oil and gas well into the 21st century as the global economy transfers to a low carbon operating model. It is vital that the environmental research community has the evidence and tools to demonstrate how this can be achieved in an environmentally sustainable manner against competing commercial and political pressures. The research community has simultaneously to aid the development of innovative technologies for sustainable use, preservation and risk management of the world's natural resources. Seismic interpretation can be used to analyse the water column, the seabed and the subsurface and all three areas need to be taken into account when analysing the effects of offshore drilling or decommissioning operations for example. The current oil and gas workforce has undergone significant reductions as a consequence of the global oil price fall but eventual recovery is very likely, and the UK has an opportunity to use this time to develop decommissioning research and practical experience with the resultant skills and technologies becoming valuable export earners for the UK economy. New technologies allow for alternative processes and uses for oil and gas that reduce environmental and societal impact. There is therefore a need to widen research in relevant upstream training and research areas so that sustainable energy and security of supply is maintained. Not having a sufficiently large and capable skill pool for the future will begin to erode the cost-competitiveness of the UKCS, thereby threatening again the viability of the North Sea which in turn is bad for security of supply and impact the country's competitive advantage for overseas business.

What is the UK's current capacity to deliver high quality training in this area?

A number of UK institutions offer relevant MSc training in this sector, but industry has realised the limitations of these courses in providing the rounded skills, independent learning, research experience and maturity that can be imparted to research students who are given the time and opportunity to access training out with the immediate focus of their PhD projects. The creation of multiple CDT/DTPs in related fields has allowed for some inter-organisational training opportunities to widen access to skills e.g. NERC EnvEXPO and Oil & Gas CDT MoU with EPSRC CDT in CCS & Cleaner Fossil Energy. The CDT in Oil & Gas has developed a 20 week programme completed over the first 3 years of a 4 year studentship and harnessing the expertise of 17 UK universities and over 40 industry and regulatory organisations. The benefits of the 4 year PhD studentship (3.5 years of research skills and experience, 0.5 years of bespoke training in a range of industry/policy making topics) in building a set of skills that cover many more key areas of industry's operations fieldwork, quantitative assessment, environmental analysis, public communications, exploration, production, risk reduction are clear and the use of the CDT in providing these through this collaborative partnership and effective training hub and spoke model is unique. This is a time-limited scheme, however, and the UK risks losing the impetus of this new way of working experienced by a group of young researchers, their supervisors and all the industry and regulatory authority representatives who have been involved in the training and/or research programs. The academic/industry/government partnerships developed provide a time and cost-efficient means of communicating across the sector to ensure that the environmental challenges are widely recognised and are a fundamental part of thinking in the oil and gas sector, whatever the background of the players or the particular activities they are involved in.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

The sector requires an ongoing supply of informed, technical experts with the range of skills required to analyse the complex interactions of earth and environmental sciences within an ever-changing geopolitical landscape in an area of operation that underpins the fundamental health and prosperity not just of society and the economy of the UK, but of every country. The security of energy supply and the development of innovative technology and processes that use the natural resources of oil and gas will be hampered or even curtailed without

continued investment in this sector. The country will lose a supply of top talent who have the potential to be the next generation of leaders in their field, be they academics, policymakers or industry practitioners. The Centre for Doctoral Training (CDT) model that encourages the largest possible pan-UK partnership fosters the cross-institution, cross-disciplinary development of communication, knowledge exchange and broad-based training and gives the best opportunity to develop scientists with awareness and aptitude to influence environmental aspects that are vital inputs to oil and gas activities. It also provides environmental and geoscience practitioners with access to policy makers, both in government and industry, allowing them opportunities through training to learn how best to present their science and evaluate it within a wider body of information. Many universities are members of two or more CDT/DTPs, and are targeting different departments within government or the same companies for support, and many experience difficulties in securing sufficient numbers of students in a particular discipline to be able to offer bespoke training to them all. Those partnerships that have demonstrated the ability to work collaboratively to open their training programs to others are also encouraging the cross-fertilisation of research, improving the research outcomes for students and end users.

What would be the impact of NERC investing in a CDT in this area at this time?

Investing in this area places the environmental agenda at the forefront of future energy & hydrocarbon-related research & training. It secures a role for geoscience at the heart of a key sector of the UK economy which has global reach, ensuring that the skills needed to explore, sustain & reduce the environmental impact of oil & gas exploration & extraction at a time of economic challenge & focus on responsible environmental management are developed and made available. The OGUK Business Outlook document gives the decline in industry staffing over the past 3 years as a reduction from 450,000 to 330,000. A number of companies were already anticipating a demographic vacuum appearing in 2020 & beyond so it is clear that an investment now in this area is key to ensuring that the correct combination of skills & knowledge continues to be available in the UK workforce to protect the country's self-sufficiency in energy supply as well as supporting the successful transition to a low carbon economy. The Oil & Gas CDT provides existing successful, tried-and-tested infrastructure & a combined research & training program encompassing the largest academic & industry CDT/DTP partnership in the UK currently. It has established reciprocal training agreements with other NERC-funded CDTs as well as developing MoUs with other RCUK CDT/DTPs in the energy & environmental sectors (EPSRC CDT in CCS &Cleaner Fossil Energy, NERCs NEXUSS CDT, DREAM, EnvEAST and SPITFIRE). It has built links between academic departments and between the HEI sector & BEIS, the Scottish Government, OGA, OGUK & global industry players. Industry partners have also been given the opportunity to work together in developing the research portfolio & training program and this has encouraged them to share their insights, experiences & resources with one another and with academia. Investing in this area gives this collaborative modus operandi the time to become the norm.

What would be the impact of NERC not investing in a CDT in this area at this time?

It takes time to create and embed new attitudes to how academia, business and the government can work together. Individuals, organisations and government departments all have vested interests which it is all too easy to follow rather than look to the wider societal gains expressed in BEIS Industrial Strategy or the UNs 17 Sustainable Development Goals. The outputs of the extraction and use of hydrocarbons impact on individuals in every society and the world is at a pivotal point in determining the strategy for oil and gas and their place not just in the worlds energy mix, but in its multiple by-products from plastic to medicines. If NERC chooses not to invest in this area at this time, it loses control of the environmental agenda in this vital space and the new shoots of co-operation in a highly competitive arena are likely to be choked by the return to a narrow focus on individual research for its own sake. The pressures to move to a low carbon economy grow at both local and geopolitical levels so there is a need for the research and operator communities in this space to be agile in developing environmentally sound tools and processes to secure the planets future. All

the benefits of the section above would be lost to NERC but yet would be available to other funders to gain the benefits of after NERCs original decision to meet the challenge of deepening government, industry, academia and societies understanding of the environmental responsibility.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

The title for this Training Priority Need is 'The application of Geo- and Environmental Sciences as Society moves towards a Low Carbon Economy'. The hyperlinks to supporting documents do not appear to function in the fields above so please see the relevant web links below:- Financial Times article by Andrew Ward - 'Oil industry struggles to fill hole left by baby boomers' https://www.ft.com/content/f0c72686-9761-11e6-a80e-bcd69f323a8b The Oil & Gas UK's Business Outlook 2017 - https://cld.bz/poC4dqe/30 The Oil & Gas UK's Environment Report 2016 - https://cld.bz/qgAn4xr/6 The Department of Business, Energy & Industrial Strategy's Industrial Strategy - https://beisgovuk.citizenspace.com/strategy/industrial-strategy/supporting_documents/buildingourindustrialstrategygreenpaper.pdf

17. Greenhouse Gases in the Earth System

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
We suggest an integrated training programme of environmental science and data management that will lead to a comprehensive understanding of the role of key greenhouse gases (GHGs) in the Earth system, and the processes that govern their dynamics in the atmosphere, ocean and terrestrial biosphere from an interdisciplinary perspective. Different aspects of GHG research are, at present, covered by different sub-disciplines and research communities, e.g. oceanography, atmospheric science, biological sciences (including ecology, forestry, soil science etc.) as well as social sciences, that have evolved separate traditions, communities, technologies, methods, practices and data stewardship standards. Future researchers need to gain a wide understanding of GHGs across different sub-disciplines and research communities. Training should enable scientist to establish links with colleagues across these sub-disciplines. In particular, they should * be trained in theoretical background on the role of GHGs in the Earth System * receive practical training in how to measure and model fluxes in water, atmosphere and earth, in the operation of multiple analysis and sensor techniques to international quality standards, * receive training to generate datasets with globally acceptable metadata, to access online data repositories and handle datasets and model outputs of large spatial and temporal scales, * be trained in the multi-faceted critical thinking for ethical, societal and technological challenges (such as geoengineering, or impacts of adaptation and mitigation on local communities worldwide).
Please evidence the training need in this area from business, policy and/or third sector users.
As part of the NERC Greenhouse Gases Emissions and Feedback Programme, we held several community and stakeholder discussion meetings between 2014 and 2017 with participants from government, industry and the third sector. Some of the outcomes from these workshops identified training needs. A particular area is the need to monitor emissions on a variety of scales, from national inventories to small industrial hotspots like landfill sites. This creates not only an opportunity for instrument manufacturers, but also for service companies that setup monitoring networks operationally and process and analyse the data. Generally, cheaper, more frequent and regular long-term datasets are needed that are internationally comparable. Therefore there is a rising demand for scientists with a comprehensive cross-disciplinary understanding of GHGs in industry and business as well as in government and regulatory bodies. Another outcome from our stakeholder interaction is the need to engage with society in more meaningful way. Practically all sectors of society, both on the level of organisations and individually, will have to contribute to mitigation efforts, adapt and change their behaviour, if GHG emissions are to be reduced successfully. This requires educators and opinion leaders who can help to develop evidence-based approaches, so that decisions in politics and the civil society are based on scientific understanding. The proposed training will therefore also be relevant for education and public engagement institutions, for example museums, science centres, science journalism, teacher training centres and similar. (see also next question)
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
One outcome of our stakeholder engagement (see previous question) was that national and international GHG targets create many new business opportunities, both for established and for startup companies. The proposed training supports these, with the potential to attract

investment from these businesses, in terms of funding and other resources (e.g. equipment, staff time). Generally, there is now a vibrant service and technology industry in mitigation and adaptation, providing monitoring and data services, with new technologies aimed at answering very specific questions being developed all the time, and new business models emerging. International knowledge exchange also creates new opportunities. While many environmental and energy technologies are quite mature in industrialised countries, their use in emerging and developing nations is patchy. Consulting engineering companies have found many fields to work in, but the international economic and legal environment can be challenging; new technologies may need decades to get certified.

How will the proposed training meet the identified demand for these skills from end-users?

There is a demand for scientists with cross-disciplinary experience in GHGs (see question 2), and the training will help scientists to develop these skills (see question 1).

What is the scientific importance of this area to the UK Environmental Research community?

Understanding the impacts of global warming and other associated planetary scale changes (ocean acidification, global greening, changes in rainfall patterns) associated with the increase in atmospheric greenhouse gas concentrations are amongst the most significant challenges facing environmental scientists today, and essential for the career of any researcher / professional looking to navigate their science, business or government work in a more sustainable manner in an era of environmental change. Quantifying GHG emissions is central to international efforts to slow their growth rate in the atmosphere, in order to mitigate the humanitarian and economic impacts of climate change, and to underpin the UK's national and international mitigation commitments.

What is the UK's current capacity to deliver high quality training in this area?

While high quality training on specific aspects or techniques for GHG research exist in many UK institutions, to our knowledge there are few training opportunities designed to give a wider perspective across the whole range of techniques. Current postdoctoral training is narrowly focussed and split between the ocean, atmosphere and biosphere research communities, which have traditionally been separate. Training does not always offer a researcher the opportunity to contextualise their work within wider spatial and temporal scales and multiple geophysical disciplines. This was highlighted by both NERCs 2012 Most Wanted II report and the Institute of Environmental Management and Assessment (IEMA)s 2014 report Skills for a Sustainable Economy that identified a continuing critical skills gap within the environmental sector. The latter cited research that identified only 13% of organisations are fully confident that they have the skills to successfully compete in a sustainable economy. The NERC Greenhouse Gases Emissions and Feedback Programme organised 2-week long International Summer Schools on Global Greenhouse Gases in 2015 and 2016; this activity will be continued in 2017 with funding from NERC's Advanced Training: Short Courses scheme. Over the past two years, we received a total of 178 high quality applications, from the UK as well as international students and young researchers working in a wide range of areas. Feedback showed that course participants found the interdisciplinary course design hugely beneficial, and that the combination of lectures, fieldwork, laboratory exercises and practical and interactive elements was stimulating, well-targeted and intellectually engaging. Our experience from these summer schools indicate a clear demand and desire for training across sub-discipline borders and a need to enable young scientists to make these connections.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

Because of substantial NERC investment the UK is in international pole position with GHG science, particularly associated with quantifying national budgets. Without additional investment in training there will be a shortage of early career researchers to continue science and technology activities, and a shortage of informed graduates who can play a

meaningful role in helping to transform the low-carbon UK economy. A CDT is required because of the diversity of sub-disciplines involved with GHG science.
What would be the impact of NERC investing in a CDT in this area at this time?
Broadly speaking, NERC investment in training will lead to a traceable impact case associated with innovation and transformation of the science and economics underpinning the mitigation of GHG emissions.
What would be the impact of NERC not investing in a CDT in this area at this time?
This is more difficult to answer. The impact would be a major knowledge gap between the needs of government departments, SMEs, and NGOs and the available environmental science workforce.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

18. Rapid Earth Movements

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
The main goal of this proposal is to build the next generation of world-leading environmental geo-scientists, with key, inter-disciplinary skills to dramatically improve our ability to control and respond to environmental hazards, one of the major challenges that NERC has highlighted for the 21st century. We will focus on Rapid Earth Movements (REM), which comprise a range of rapid, sudden movements of the Earth surface, including earthquakes, landslides and volcanic eruptions. These movements are provoked by tectonics, surface processes and their complex interaction with the morphology of the landscape, its lithology and climate. None of them can be accurately predicted, at specific locations and at the timescales that are useful for humans; even if these predictions were possible, these movements would still represent a major threat for infrastructures. The science underpinning our ability to monitor areas at risk, establish REM recurrence times, predict their magnitude and effects on the landscape if they were to happen, still require a wealth of fundamental, cross-disciplinary research that this programme aims to produce. Prospective students will be expected to be graduates in Earth Sciences/Geology and/or Environmental (geo)science, with a strong knowledge background in geology. Uniquely among peers, they will receive multi-disciplinary training in a series of techniques, including collecting geological, geospatial and isotopic data relevant, crucially, to the time scales at which REM recur (101-105 years); probability and statistics, to be able to understand and code numerical models of risk prediction and quantification, so to improve model robustness and therefore utility; science communication and knowledge exchange among academics, industry, policy-makers and communities, even in situation of distress. Training in specific subjects will be tailored to the needs of each student, taking their background and objectives of their research into consideration.
Please evidence the training need in this area from business, policy and/or third sector users.
REM are extremely important phenomena, both in terms of understanding the tectonic and surface processes that drive them and as major threats to human lives and infrastructures. Current research has clearly demonstrated that, despite the fact that REM occur in a matter of a few seconds, their 'build-up' lasts for possibly up to thousands of years and it is at these long timescales that these processes need to be understood, despite the fact that risk assessments need to be informative at a much shorter timescale (years to decades). Numerical models used to quantify and predict risks are based on probabilistic analyses, the implications of which are often not appropriately explained to the non-academic community. During this programme, we aim to bridge two fundamental knowledge gaps: 1. We plan to train students in data acquisition, data handling, probability and statistics, so that the geoscientists that collect the data used to test the numerical models of risk prediction have a firm understanding of the mathematical laws underpinning the model. This specific training will permit the students to fundamentally advance our knowledge of the uncertainties associated with the method/s used and how they are reflected in the numerical models and, more in general, in the research conclusions. 2. The research need to be effectively communicated to the end-users. We plan to train students in knowledge exchange to facilitate the flow of information between scientists, policy-makers and business, who deals with R.E.Ms and are the potential employers of our students. To facilitate this communication, the programme will include a significant number of CASE studentships and work placements in appropriate companies and/or agencies. In collaboration with science communicators and psychologists, we aim to train students to efficiently communicate with third sector users, to bring the results of this research to the communities living with R.E.Ms, to enhance their quality of life.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
Risks from REM are relevant in the UK (eg landslides closing transport links) and a range of agencies will be enlisted as collaborators (e.g. Scottish Water; Transport Scotland, British Geological Survey). Geotechnical and engineering private companies, which are often called to remediate the damages caused by REMs or have their services disrupted by REMs will also participate to the programme, supporting CASE studentships (e.g. contacts have been taken with SSE). These companies and agencies will be the natural hub for our students to find employments, once their training is complete. A requirement of a systematic training in quantitative geomorphology has been highlighted in meetings with private companies interested in recruitment (e.g. BAM Richies and Atkins); this field that has been highlighted as one of research Excellences of our School. However, the magnitudes and frequencies of risks are significantly greater in other locations worldwide, particularly in ODA countries. We will build on collaborations in Europe (Spain, Italy), SE Asia (Indonesia, Philippines) and Africa (Malawi, Uganda) to expand the doctoral training programme and to instigate further projects. These collaborations will lead to international student recruitment and funding from UK and international agencies (e.g. RCUK Global Challenges fund; Newton Fund), that aim at applying the knowledge acquired through this programme. The impact that REM have on human societies may be studied in collaboration with colleagues in Economics and Politics. The necessity to educate and communicate REM related risks to the population may require the involvement of Psychology and Media Studies; we also envisage collaborations with Archaeology. These new collaborations are expected to open a series of new partnerships with business, but in particular policy makers and the third sector. These unusual collaborations will provide a unique training, enhancing students attributes for future employment.
How will the proposed training meet the identified demand for these skills from end-users?
In the recent years, environmental agencies and private geotechnical and geo-engineering companies have probably become the most important potential employers of graduate and post-graduate Earth scientists. They require geoscientists that are highly skilled in specific attributes (e.g. geological mapping of hard rocks and sedimentary/soil cover; numerical modelling, database management, GIS), but also in those more general, transferrable qualities such as problem-solving and lateral thinking, team-work, communication and self-motivation. At the same time, new technologies have become widely available (e.g. the use of tablets for geological mapping, powerful desktop computer for large dataset handling) and probabilistic forecasting of likelihood of REMs in a particular location has improved greatly, as data relevant to the long time scale at which REMs recur become available. There is, therefore, the necessity, for students to be trained in these new methods and tools, acquiring, at the same time, specific and transferrable skills to build their unique and sought-after attributes. Given the high societal impact of REMs, students will be trained in effectively communicating the risks, impact and mitigation of REMs to the third sector and policy-makers, to reduce human suffering and catastrophic situation where geoscientists may be accused of mis-informing the public (e.g. the conviction, now cleared, of geoscientists in Italy for manslaughter, during the L'Aquila earthquakes in 2012). The CDT we are proposing aims at offering this training, across academia, industry (through work placements and/or industry-lead workshops) and media studies. The University of Glasgow and the other that will be involved in this CDT have an excellent track record in training students as they have been the hub of many post-doctoral training programmes, funded by a series of agencies, including ERC and RCUK.
What is the scientific importance of this area to the UK Environmental Research community?
REMs are major geo-hazards that can significantly damage infrastructures, economies and societies. Their impact, however, is usually greater in poorer countries (e.g. ODA), due to

population density, preparedness, education and quality of the infrastructures. It is therefore the duty of the UK environmental research community to improve our understanding of the Earth processes and play a leading role in tackling these global challenges. The students will be trained in combining different, state-of-the-art techniques (from remote sensing to the isotopic techniques) that will monitor the REM on a continuum of timescales, interrogating each dataset to determine how these phenomena progress in time. Remote sensing (InSAR, LiDAR, Structure-from-Motion Photogrammetry and others) analyses will be used to constrain the effects of REM on the landscape, at the timescales at which they occur. To this, we will combine cosmogenic isotope inventories to identify magnitude and recurrence of events in the distant past, using the facilities and combined expertise of the Universities and laboratory facilities that are part of the CDT. We will in particular build on our track record in investigating fundamental questions in the applications of these methods, defining the uncertainties and, therefore, the realm of applicability of these techniques to such complex phenomena. This research will fundamentally advance our knowledge of 1. the uncertainties associated with the methods used and how they are reflected in our conclusions and 2. recurrence time and magnitude of past events, to quantitatively inform risk assessment plans. This research will have an extremely high academic impact, resulting in publications in international journals and contributions to prestigious conferences. The CDT will deepen existing collaborations between Schools and Universities, fostering new ideas for further funding (e.g. RCUK Global Challenges scheme, Leverhulme Trust project grants, the Newton Fund).

What is the UK's current capacity to deliver high quality training in this area?

The UK has an excellent, world-wide recognised geoscience research community that has been providing training in their specific subjects for many years. The training covers basic and applied research, monitoring, surveying and understanding the landscape and the Earth processes that underpin its evolution, using a series of state-of-the-art techniques. The Cosmogenic Isotope Analysis Facility (NERC-funded) hosted at the University of Glasgow, for instance, is a prime example of such facilities, producing data that, among other applications, have been successfully used to assess the occurrence and magnitude of REMs, crucially at the time scale at which they recur. If the UK aims at remaining at the forefront of Geoscience, investments in the new generations of highly skilled geoscientists need to be sustained. The nature of the global challenges, as highlighted by NERC, requires an increasingly multi- and inter-disciplinary research, where the realms of the physical and societal worlds are intertwined. Although the focus of the proposed CDT could be ascribed to basic research, as we aim at investigating the fundamentals of the processes that drive REMs, the strategy behind the programme is to provide answers that help society to become more resilient to these geo-hazards and, more in general, improve quality of life. With this programme, we propose to build, through training, a new figure of a geoscientist, as a highly skilled professional, capable of identifying routes through which their research can benefit society and confident in communication their findings at different levels, across academia, through industry and third sector. The highly demanding aims of this project require Universities with proven, excellent records in training students in specific technical skills, including communication, to unite and build a community of new geo-scientists that benefit from working in a team and from the combined expertise that are available across the CDT.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

There are three main reasons why the NERC CDT is the most appropriate format for the proposed training: 1. the ambitious aims of the programme require a united effort from different Universities within the UK. The students need to have access to the state-of-the-art research facilities that are hosted in different research Institutions. The required training requires a combined scientific expertise that is simply not available in only 1 institution. The students will highly benefit from being part of a big team hosted in different parts of the UK,

but also part of their own University-based post-graduate communities. In this way, they will have access to a plethora of courses that one University only could not afford. The academics will also benefit from the scientific collaboration with colleagues from other Universities, reinforcing their link and providing the opportunity for fostering new research ideas; 2. the research within the CDT has a strong applied aspect, both in terms of training students to work in industry and agencies, but also in terms of research outputs. This training can only be achieved if the companies are actively involved in the programme, directly benefitting from it, both in short and long terms. The CASE studentships are the perfect mean to achieve this aim. 3. Each project will involve supervisors from different Universities and the production of data, some of which are quite expensive. The possibility of directly applying for consumable costs and/or for the organization of short courses, conferences and workshops will ensure that the students are comfortable in knowing that the limits to achieve their objective are only dictated by their hard work. The stipend, being one of the highest available, insures that students can fully dedicate themselves to their research, with no financial worries. This peace of mind, however, will not detract supervisors to encourage and train students to apply for further funding.

What would be the impact of NERC investing in a CDT in this area at this time?

NERCs strategic research aims at addressing key science challenges and priorities for the 21 century; REMs are a key science challenge and, with climate change having a possible impact on some geo-hazards recurrence time, a priority for our century. Understanding the science underpinning our ability to monitor areas of risk, establish REM recurrence times and predict their magnitude and effects on the landscape and society, if they were to happen, are the scientific aims of this CDT. In general terms, these are the goals that NERC has set up for the incoming years. Investing in this CDT, therefore, would be a strategic choice, as it would support our scientific endeavour to understand Earth processes and manage REMs related natural risks. The CDT will produce world-leading scientific results that, for their general importance, will be published in international journals and important conferences. The CDT will also create a strong collaboration among several, excellent Universities and industry, policy-makers and the third sectors, including directly affected local communities, which will ensure a high societal impact of our research and foster a sustained knowledge exchange amongst the different parties. Given the potentially disastrous effects of REMs in ODA countries, the research produced by the CDT will be a solid base for the Global Challenges Research Fund. In terms of training, it is our aim, following the requirement of the job market, to move away from the idea that PhD students are the academics of the future, but prepare a new generation of professionals that will be successful both in academia and industry. The impact of this new training will be direct on the students that will benefit from having a wider, multifaceted preparation to their future career. We will, however, expect our remit to become quite common among other post-graduate training programmes.

What would be the impact of NERC not investing in a CDT in this area at this time?

It would certainly be a lost opportunity, which, on the long run, could be quite costly. REMs are a global challenge, as they have a profound impact on the lives of people worldwide and for this reason, understanding their occurrence should be a key priority of any environmental research community. The CDT represents a very cost-effective way to achieve the strategy goals that NERC has highlighted in their documentation. REMs are relevant in the UK and their associated risks have a significant economic impact on British society: these effects could be quantified, predicted and decreased by the studies proposed in the CDT. REMs, in particular earthquakes and volcanic eruptions produce a much more impending risk for other countries, in particular in the developing world, where the lack of suitable infrastructures and education put people more at risk. In order to increase the skills and knowledge of these developing countries, though, for instance a Global Challenge Research Fund, we still require a wealth of fundamental, cross-disciplinary research that this CDT aims to produce. REMs are also very relevant for other developed countries (e.g. USA, Japan and southern Europe) and, for instance, it is not a surprise that geo-hazards are also a key priority for the

European Geology for Society programme; it is important that the UK maintains the world-leading position in geoscience that it has acquired over the years; this primacy can be kept only by sustained investment in research, but crucially in geoscience skills.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

Although in its infancy, this programme has been thought to involve some of best Universities in the UK. With the University of Glasgow, the School of Geographical and Earth Sciences (Dr. Persano and Prof. Hoey) will be leading the consortium, in tandem with the Scottish Universities Environmental Research Centre (Dr. Fabel), seeking collaboration with colleagues in the School of Engineering, Mathematical and Statistics, and Economics. Colleagues at the University of Newcastle have expressed a keen interest in the programme, as in Plymouth. We are seeking other partners (e.g. Durham and Manchester). Non academic-collaborators, industries and agencies have also been approached and they are keen to participate (e.g. Scottish Water; Transport Scotland, British Geological Survey, SSE, BAM Richies). We are confident that we will have the critical mass to make of this programme an extremely very good success.

19. Earth Observation for Geohazards and the Cryosphere

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Earth Observation (EO) uses measurements from satellites, aircraft and ground-based instruments to monitor and assess the state of the planet. This submission by CPOM and COMET focuses on geohazard and cryosphere EO. EO is becoming increasingly sophisticated with the development of new satellites and high-tech instruments. The European Space Agency (ESA) is at the forefront of major EO advances such as the Copernicus programme, and Sentinel-1 in particular has set a high benchmark for future satellite radars. Its open data policy is a huge step forward in encouraging scientific and commercial exploitation of the data. CPOM and COMET have worked closely with ESA on the design and operation of these missions, as well as data processing and interpretation. Significantly, the polar-monitoring CryoSat mission was originally proposed by CPOM who have subsequently played a leading role in the analysis and validation of CryoSat data. COMET meanwhile works with ESA on the Sentinel-1 acquisition plan, focusing on ground deformation. COMET has developed a new system, LiCSAR (http://comet.nerc.ac.uk/COMET-LiCS-portal/), to process the vast amounts of data generated daily. LiCSAR is now providing high-resolution deformation data for the entire Alpine-Himalayan seismic belt. The benefits of EO are increasingly familiar, but for society to benefit fully requires a community of competent users who have the requisite skills and understanding. A comprehensive training programme would make vital links between the data and its application, covering multiple EO techniques (e.g. interferometry, altimetry, GPS). It could include theoretical principles, current and future missions, processing algorithms, accessing EO archives, real time data and higher level products, tools and methods for the exploitation of EO data, visualization and communication skills, and EO data processing and product demonstration, including limitations of the data and its use in practical applications.
Please evidence the training need in this area from business, policy and/or third sector users.
The difficulty of recruiting people with requisite skills is acknowledged within the EO sector. The UK Space Innovation and Growth Strategy (2010) sets out the need for a skilled EO workforce, noting that growth will create jobs requiring postgraduate levels of training, specifically in the handling of data. The 2015 Strategy Update also stresses the importance of growing skills for space-related businesses. Growing demand in the downstream application of EO data is also identified in the UK National Space Technology Strategy (2011). A 2015 Royal Society report on EO meanwhile reinforced that the UK needs to develop its current skills base to make the observations and translate them for policy or practical use. In 2016, a House of Commons Select Committee Inquiry into Satellites and Space identified skills shortages, including in data analysis, as factors that could prevent the sector reaching its potential. Several representatives from across the EO community, including CPOM and COMET, gave evidence (http://bit.ly/2oMIx2A). Notably, UK Space highlighted the challenge of creating a workforce capable of analysing the massive volumes of data coming from the Copernicus programme and its translation into practical applications. Both CPOM and COMET are making significant progress on this, but the sheer data volumes necessitate further investment and support, including in skills development. Skills shortages were also identified as a reason for the slow uptake of space services across Government and the public sector. Professor Ian Boyd, Chief Scientific Adviser at DEFRA, stressed the need for skilled people to process the data alongside private sector

involvement to develop the tools which make the processing possible. The third report of the Inquiry (http://bit.ly/2nStVuV) clearly identifies a lack of skills as barrier to further growth in the sector, with current initiatives being insufficient to tackle the magnitude of the problem.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
There are numerous opportunities to develop applications from EO data, particularly from the Copernicus programme. Examples from CPOM and COMET are set out below. Near real time Arctic sea ice data from CryoSat-2 radar altimetry. This information, available on the CPOM data portal (http://www.cpom.ucl.ac.uk/csopr/index.html), has potential use in policy development, military operations, tourism, exploration, and search and rescue. The Met Office has also expressed interest in using data to improve predictions of regional climate. Satellite remote sensing of volcanic emissions. Data from the MetOp Infrared Atmospheric Sounding Interferometer (IASI) currently displays SO2 concentrations in the atmosphere (http://www.nrt-atmos.cems.rl.ac.uk/), but is being expanded to include provide volcanic ash with potential applications for the aviation industry. The service has already monitored a number of larger volcanic eruptions, including VolcÃ¡n Calbuco, Chile (April 2015), Mount Etna, Sicily (December 2015) and PopocatÃ©petl, Mexico (January 2016). Provision of high resolution maps showing ground movement from Sentinel-1A (http://comet.nerc.ac.uk/COMET-LiCS-portal/). This is helping both scientists and policy makers to assess how and where tectonic strain is accumulating/where ground is deforming around volcanoes, with potential to improve the understanding of geohazards. Sentinel-1A interferometry data was also used to measure ground movement across the entire eastern half of Nepal following the 2015 Gorkha earthquake. Information was fed to DFID, GO-Science and SAGE, advising them on the event. The Ice Sheet Mass Balance Intercomparison Exercise (www.imbie.org). This combines satellite estimates of ice sheet mass balance with the overall aim of producing a community assessment of Greenland and Antarctica's contribution to global sea level rise. IMBIE has contributed to assessment reports of the Intergovernmental Panel on Climate Change (IPCC).
How will the proposed training meet the identified demand for these skills from end-users?
The UK Strategy for Earth Observation from Space (2013) emphasises the need for EO data, products and services that are easily accessible to policy makers, business users and wider consumer markets, noting the need to prioritise UK leadership in EO (including climate science) and development of Synthetic Aperture Radar technologies such as InSAR (including for natural hazard management). Training in EO tools and techniques will provide the skills and capabilities to deliver high quality EO products from raw satellite data in a timely and reliable fashion. The potential of techniques such as InSAR is already recognised by geospatial services providers, governments and NGOs, and the insurance industry (via the Global Earthquake Model) to map ground deformation, for example in geohazard assessment and management. Demand for improved sea ice information in the Arctic in particular is growing as a result of climate change and its impact on environment and human activities. The observed decline in Arctic sea ice extent and increasing demand for natural resources are key mechanisms driving human activities in the Arctic. By providing the skills needed to develop and deliver operational services, training will further bridge the gap between academic research and practical applications, and also raise the profile of EO across multiple sectors. NERCs involvement will meanwhile provide these sectors with confidence in the quality of the training as well as a focal point for recruitment. Ultimately it will ensure that these sectors are well placed to exploit the growing volume of data collected by satellites for societal as well as scientific benefit, incorporating the science into policy and decision making.
What is the scientific importance of this area to the UK Environmental Research community?
EO techniques are already addressing critical gaps in our understanding of the Earth

system. COMET and CPOM provide national EO capability to the UK environmental research community regarding geohazards and the cryosphere. Our scientific leadership is recognized nationally and internationally, not only in terms of scientific discovery but also regarding the development and exploitation of EO missions, technologies and techniques. COMETs achievements include investigating the cause and effects of major earthquakes, such as the continuing seismic hazard associated with the Gorkha (Nepal) earthquake in 2015, and the Apennines (Italy) and Kaikoura (New Zealand) earthquakes in 2016. Our measurement of volcanic deformation and emissions has informed action both during volcanic crises and in between eruptions. COMET also provides a number of services and datasets that support the national and international environmental research community, including on various earthquakes and faults, volcano deformation, global volcanic SO2 monitoring, and maps of ground deformation produced by LiCSAR. CPOMs monitoring of the polar regions has meanwhile produced the first near real time measurements of Arctic sea ice thickness, available through the CPOM data portal alongside outlet glacier ice velocity measurements derived from Sentinel-1, and is shortly to be joined by information on the Antarctic and Greenland ice sheets. The data has been used by climate change scientists, the sea level and ice sheet geodetic mass balance communities, and glaciologists. CPOMs leadership of the first community assessment of ice sheet contribution to global sea level rise (IMBIE) has also improved confidence in measuring both ice sheet mass balance and its climatic impacts, including sea level rise. This EO national capability, and the datasets and information it produces, supports a broad range of environmental research within the UK and beyond.

What is the UK's current capacity to deliver high quality training in this area?

Results of EO studies are commonly disseminated within academia (via scientific journals and conferences) and, where they are of public interest, the mainstream media. Developing a skilled workforce for the EO requires a more targeted approach, taking advantage of technical expertise, knowledge exchange, tailored communications, and joint working between researchers and end users to find new applications for the data and products. It is also important to note that EO start-ups require more than generic business skills and therefore bespoke training. Through COMET and CPOM, several UK universities have the capabilities to deliver high quality training in EO focusing on geohazards and the cryosphere. Spread across nine university departments, both research centres attract high quality staff, students and research contracts from across the UK and internationally. CPOM and COMET have delivered a number of short courses in recent years, including a week-long collaboration with ESA on advanced training of the cryosphere (http://seom.esa.int/cryotraining2016/). This was oversubscribed by a factor of two, evidencing the demand for EO cryosphere training. COMET also hosted a shorter workshop focusing on InSAR techniques (http://comet.nerc.ac.uk/comet-insar-training-workshop-2016/), while scientists from both centres have contributed to external training courses such as the ESA FutureLearn course on EO from space and UNAVCO InSAR courses. The capacity for high quality EO training therefore exists, however provision is currently limited to a) short courses for early career researchers, meaning that researchers often gain the skills needed to take advantage of EO programmes and data in a piecemeal way, and b) developing academic research capabilities, rather than working with industry partners to fill the skills gap outside of academia. As above, the latter requires more targeted knowledge transfer initiatives and facilitated business engagement.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

The UK Space Innovation and Growth Strategy (2010) states the need for RCUK to influence skills provision and development of doctoral students and researchers. A CDT would be able to develop researchers who are able to not only handle EO data, but also to maximise opportunities to develop new knowledge and new goods and services which will help grow our economy. With NERC both funding national capability in EO and facilitating

the coordination of the academic EO community, a NERC CDT would provide a focal point for stakeholders to engage with the UK academic sector. Moreover, a CDT could bring together various EO disciplines and technologies, focusing on user demand rather than specific research topics, providing a broad, responsive and flexible approach. A NERC CDT also represents a coordinated approach to public investment in the space sector. It would support DEFRAs EO Centre of Excellence, which is aiming to ensure that observations, including those from the Copernicus programme, are used across DEFRA to their maximum potential; the use of EO by DECC as cost-effective information on the climate and environmental resources for effective policy making; and DFIDs use of EO in monitoring geohazards and the implications for vulnerable communities. Developing capabilities within the UK via a NERC CDT will help to ensure that the benefits of public investment in EO, including intellectual property and competitive advantage, are supported, facilitated and coordinated. It will also highlight UK expertise, data and products to potential investors.
What would be the impact of NERC investing in a CDT in this area at this time?
Investment in an EO CDT would create a cohort of highly skilled postgraduate students who can deliver a significant return on the research investment to the UK economy, including in national capability funding. This pool of NERC-funded students will not only have exemplary research skills, but also, the leadership, management and communication skills necessary to build strong relationships between industry and academia. The outcome would be greater UK leadership and capabilities in processing, analysis, quality assurance and control, modelling and visualisation of space data for environmental research as well as geohazard monitoring and climate applications. A CDT would also provide a focal point for recruitment into the UK space sector, potentially facilitated by links to the Satellite Applications Catapult and UKSA. This highly skilled workforce, with its knowledge of the EO science base, could also prove a valuable asset in influencing the work of the space agencies, including the design of future satellite missions. In addition, a CDT would provide academics with insight into the growing EO sector, and allow industry to be directly informed by the latest research. All of this will increase the potential to deliver impact from NERC-funded research, by creating new products and services based on EO applications as well as underpinning policy making.
What would be the impact of NERC not investing in a CDT in this area at this time?
As above, building sustainable markets for EO data and services is clearly dependent on providing high quality products in a timely and reliable fashion. Without a highly skilled and adequately qualified (i.e. to PhD level) workforce who both understanding the scientific basis of EO and are trained to develop and deliver operational services from satellite data, it is difficult to see how the UK will be able to both remain a leader in this field and to exploit the many opportunities presented by the rapidly evolving EO sphere.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

20. Interdisciplinary Water Science

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Water is frequently compartmentalised by sector (irrigation, energy production, drinking water, sanitation, etc.) with research carried out by single disciplines (engineering, physical geographical sciences, environmental economics, political science, etc). Such an approach often prevents opportunities from being realised, connections made or appropriate holistic solutions adopted. We have identified an urgent need to develop an approach that allows water-related problems to be assessed across disciplines, i.e. interdisciplinary research and innovation. Interdisciplinary training through research will allow the new generation to use the skills acquired from tangible disciplines, to deliver an impactful solution and distinguish them from other trainees in other HE systems. There is a need for PhD level employees who can overview and articulate the broader water challenge and be able to provide scientific and technical solutions. Environmental problems frequently require collaboration between; engineering, policy, economics, consumers, design, IT/technical. We need people who can transverse between the very different fields to achieve results across catchments, geographic boarders, and ecological regions. The interdisciplinary training proposed would retain depth of subject in the NERC core areas, paired with breadth of interdisciplinary elements. Interdisciplinary water research training provides an opportunity for NERC to join hands with additional UKRCs to boost specific skills that will deliver holistic solutions, for example a) communities responsiveness (social) and resilience (engineering) to risk of water scarcity or extreme events (floods & droughts), b) through environmental impact assessment, emphasising the sustainability of the solution, reduced pollution risk, & additional benefits to health & wellbeing; & c) economic impact, including willingness to pay for water services, income generated, installation/operating costs, energy requirements, etc.
Please evidence the training need in this area from business, policy and/or third sector users.
Skills in evaluating finance models and insurance relating to Natural Flood Management & Green Infrastructure (GI). Ability to undertake environmental appraisal and experience in protected species surveying, combined with the understanding of policies adaptation which is needed in the different locations. More cross-sectoral risk assessments: municipal and industrial wastes impact on rivers ecosystems, cities benefits from GI. Business development, production of bids and tenders, project & budget management, and managing client relationships. Completeness and compatibility between data formats, planning and overseeing complex, sensitive projects and data management. Incorporation of advice and technical input into hydro-ecological investigations. Climate change, environmental and chemical risk expertise with strong IT and economics capability. Monitoring & analysis to separate the effects of climate & other environmental changes on populations & communities across the full diversity of UK environments. Ability to collect information from the different sectors, as; the effectiveness of adaptation strategies, including how ecological networks function in a changing climate. References: Jonathan Abra, Knowledge Transfer Manager (17/3/2017); Consultation paper on Innovation Engagement Event for Water; Knowledge Transfer Network/Innovate UK; NERC, M&S, WWF Water Risks Workshop Summary Papers (13/4/2016) provided by Jo Howorth, Corporate Partnership Manager, Univeristy of Leeds; Amanda Crossfield, Lead Advisor for Climate Change Adaptation at Yorkshire Water (29/3/2017) direct conversation at Water, water, everywhere event; Fredrick Royan, Vice President, Global Environment & Water Practice, Energy & Environment, Frost & Sullivan (13/10/2016) 2016 Global Water Market Outlook: Water and

Wastewater Treatment Market, European Network Rehabilitation Market, presentation to British Water International Forum; Arup (2015-2016) Global Water Annual Review

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

Our end-users research collaborators include consultancies, water utilities, environmental regulators, technology start-ups and third sector organisations, who demand diverse skills for their future employees (ARUP, Yorkshire Water, JBA, Environmental Agency, the MET Office & water industries). These organisations are working on progressing model improvements, scaling up of techniques and/or processes, security for data-sets. Our University is hosting current CDTs and DTP with over 30% CASE investments from partners. Further demand for PhD training is in line with industrial sector growth globally, and the already strong demand for the skills development provided by an interdisciplinary water CDT. This will attract the funding of specific projects, by the reassurance that the solutions they seek will be tackled from many research angles. PhD students in a CDT will know where to seek data, how to store, manipulate, digest and report it through accessible translated science, to enable stakeholders to incorporate science into the decision-making processes. Recognised gap in NERC PhD skills, broadened via other disciplines such as Engineering, Economy, and sociology will answer the challenge. The industries by-in intensifies as we plan the PhD research project to match their priorities. The collaboration through PhD research creates opportunities for the industries such as; investments in a qualified future employees as a three-year committed individual is placed to solve their priority. Working alongside the industries timetables and budget planning will enable their investments in future CDTs, for example, via Industrial CASE. The established collaboration with the academic sector, through both the non-academic end-users together with interdisciplinary sponsorships by NERC, will create an Interdisciplinary Water Centre for Doctoral Training, which will confine and prioritise the demand and will deliver the necessary training which will overcome the gap.

How will the proposed training meet the identified demand for these skills from end-users?

Our collaborators in the water sectors work constantly with our academics to accomplish a comprehensive understanding of impactful scientific questions that inform PhD training needs. We seek to combine in-depth training in a core NERC facing discipline with broader multidisciplinary awareness which enables the researcher to fully appreciate and contextualise the problem. From a skills development perspective end-users are looking for technically aware individuals, ones who can articulate vision, communicate to different audiences, & provide leadership in their sector of choice. Our partners need employees who can confidently present convincing business cases to support implementation of innovative water technologies for flood risk management, evaluating river water quality & removing pharmaceuticals from waste streams. People who can design and undertake ecological and arboriculture surveys to relevant quality standards, who can advise the UK government regarding opportunities for protecting the highest value habitats through the post-Brexit alternative to the Common Agricultural Policy, incorporating socio-economics ecosystem services to a research. Dedicated interdisciplinary training will illustrate how the different disciplines have always needed to work in harmony to achieve improvements to water and wastewater provision. The missing sections in the current training can include sessions on; types of data to collect answering an interdisciplinary hypothesis, how to collate & digest it, to present it to the stakeholders, what kind of contribution could be given to an environmental challenge, using interdisciplinary data-sets. The interconnectedness of water problems, political will and innovative infrastructure investment is not new, but a new generation of experts will benefit from a PhD grounded in the strong tradition of interdisciplinary the water industry naturally fosters.

What is the scientific importance of this area to the UK Environmental Research community?

The UK provides international leadership in environmental science, and a water related CDT would enable a new generation of water researchers who are placed to build on this The UK water research community is internationally recognised for our high-quality skill and expertise. By investing in interdisciplinary water research training, the exceptional skills and insights gained can be shared with the next generation, providing a network of UK and international alumni who can propagate the UKs high standards of evidence based action and water security. The issue is one of foresight and legacy planning, as this type of programme would be expected to produce high quality researchers that will solve tomorrow's problems. The impacts of Brexit may cause a dearth of water scientists in the UK in the future which will present challenges in terms of employer demand. The connected approach to water, land, air and water, energy, food is growing, and extending the scope of research more broadly to yield novel insights. The vital need of scientific importance is for the problem solvers of the future to have a depth of understanding regarding water and interdisciplinary experience in creating impactful change.

What is the UK's current capacity to deliver high quality training in this area?

The UK currently has a limited capacity that exists as uncoordinated pockets within different universities, for providing truly interdisciplinary high quality water research training to post-doctoral level. There is provision at an individual level, at times at project level so a small group can benefit from coordinated training but there is no genuine, fully supported cohort of CDT PhDs being trained. A holistic overview of real-world challenges is needed, to allow fruitful collaboration between researchers from socio- economic-engineering sciences and the researchers from environment-climate-bio-ecology disciplines. In this way, PhD researchers will be able to share their expertise and experiences, learn from each other and create synergies in their training efforts. In addition, the water industry is growing and with it the provision of water researchers and professionals needs to keep pace. An interdisciplinary water CDT will enable the space for interdisciplinary, cross-sectoral discussions within PhD student's cohorts, that will enrich their specific projects and future research agendas. The actual research tasks benefit from a comprehending input from the parallel disciplines, and the students will emerge as the future generation of interdisciplinary educators in time to support the 2030 delivery deadline for many of the key sanitation and clean water Sustainable Development Goals in SDG 6. The cohorts of PhDs who will participate in the CDT will achieve the kind of critical mass within a sector and across sector to help achieve the kind of stable, long-sighted activity which is so urgently required to address global water challenges. With directed proper interdisciplinary training in water, students will be able to incorporate to environmental studies interdisciplinary knowledge, which is needed for their personal development (creative out-of-the-box, risky thinking) into their projects.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

The University of Leeds is home to 10 active CDTs and DTPs and has excellent past experiences for delivering training through the mechanism of Centres for Doctoral Training (with an 93% completion rates). The experiences gathered in most recent years, evolved the local transferable skills unit (the Organisational Development and Professional Learning), which provide bespoke trainings to employees and to CDT and DTP cohorts, alongside the contacts which were established with professional training providers outside the university. A CDT training format brings the cohorts of students together, to brainstorm, visit field sites, create reports, events and activities as a group, parallel to their thesis topics and making open and transparent contributions to each other. This is a particularly strong platform to provide PhD students with interdisciplinary training, as the time and space the CDT allows them helps them understand how they can implement interdisciplinary solutions to the challenges they are exploring in their projects. The strong input from the different sectors, allows the measurement of the creativity aspect, as is the visionary leadership, and ability to take risky assumptions and examine them scientifically, to influence the formation of strong

solutions. A CDT enables this alongside core training provided by our University's transferable skills development units and a multidisciplinary supervision team. We would also work closely with end-users to define the training programme and to select individual projects which balance technical need of the end-user with the wider training requirement. Our approach is to develop research projects within a CDT programme underpinned by a unifying strategic framework based on the evidences which we have collected.

What would be the impact of NERC investing in a CDT in this area at this time?

Investing in an Interdisciplinary Water Research Centre will place NERC internationally with funders who rapidly picked-up on the global need to respond to end-users problems in water. In addition to the race to find technical solutions to the critical need for water (for: storage, supply, environmental natural service, industrial requirements and more), which are mostly resourced from other UKRCs, rather than NERC, the environmental considerations are the ones that defines the direction of the impact. Facing a changing climate with a growing population, highlights the need for flexibility in finding solutions and this entails the broadening of the focus to other resources, such that arrive from scientific inputs from the tangible disciplines and communicating these findings in the form of evidence to leverage required change in behaviour, in investment, in processes. The impact of such an investment from NERC will allow the other disciplines to align the solution and sharpen their impact from one hand, and from the other hand, allow the improvement of the scientific literacy of the environmental terms within the disciplines which do not use environmental terms, and thus improve the communication and the collaboration between the fields.

What would be the impact of NERC not investing in a CDT in this area at this time?

Should NERC decide not to invest in an Interdisciplinary Water Research Centre, there might be an impact on; the end-users (hence the economy, trade, and competition), the society (slower solution delivery), the environment (due to lack of understanding of the all-encompassing factors which compose an environment). It is now well acknowledged that the funders would like to see more applied science, as this can be seen continuously in calls for projects funding. In addition, job descriptions of many end-users call for entry level employees who have interdisciplinary perception and experiences. Once the potential employees lack this training, they are not equipped to meet the opportunities, and therefore will not meet all the needed requirements. Therefore, in readiness to the industry acknowledged gap in the training, the momentum is there for NERC to invest in interdisciplinary training in Water Sciences.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

21. Ecology of Adaption to Environmental Change

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
We propose a training priority in the ecology of adaptation to environmental change. There is a pressing need to better understand the mechanisms that drive adaptation at molecular, individual, population, and ecosystem levels. Here, there are identified skills gaps in both field- and laboratory-based science. There is also a need for people skilled in multi-disciplinary working and translating research into practice. Training will combine theory with data collection and analysis, with an understanding of the mechanisms of adaptation and translating research into action as core goals. Training will be provided in the following areas: Experiment design, field observation, sampling and monitoring skills Species identification Development/use of GIS, remote sensing, and satellite tracking tools Microbiology and microbial physiology Biogeochemistry Application of laboratory techniques including anaerobic digestion, next generation sequencing, microbial community typing, HPLC, GC-MS, and IRMS Statistics and ecoinformatics, linking theory and data In addition to gaining subject-specific skills in these priority areas, there is a need to engage with stakeholders to identify relevant research questions, and address the knowing-doing gap. For example, linking field- and laboratory research and real-world action such as species conservation and bioremediation. Therefore, studentships would be developed in consultation with business, policy and third sector partners, and with whom students would undertake internships to facilitate knowledge transfer and develop transferable skills. The training priority that we have identified is distinct from existing NERC CDTs. In particular, the Modelling and quantitative skills in ecology and evolution CDT provides specialist training in data analysis, but does not focus on understanding the mechanisms of adaptation to environmental change, nor have an emphasis on engagement with stakeholders as we envisage.
Please evidence the training need in this area from business, policy and/or third sector users.
The prosperity of the UKs environment sector depends on the supply of people with specialist and transferable skills to tackle the challenges posed by environmental change. This requires researchers skilled in field observation and sampling techniques, and laboratory analyses to establish baselines from which to assess future change. Moreover, there is a need to understand the mechanisms that facilitate adaptation to change. Such an approach would seek to identify processes that can provide solutions to help society manage environmental change. For example, skills in microbiology are needed to unravel the effects of environmental change on animal, plant and microbial diversity and impacts on ecosystem function. Similarly, skills in species identification and monitoring are needed to quantify changing species distributions and to manage the threat from invasive species, including the establishment of agricultural pests and vectors of emerging diseases. An interdisciplinary approach and engagement with stakeholders is critical to ensure innovative approaches and translation of research into practice and to influence policy for managing environmental change (Sutcliffe & O'Reilly 2010; IEEM 2011). Indeed, the void between research and real-world action to address environmental change is an example of the knowing-doing gap (Pfeffor & Sutton 1999; Knight et al. 2008). The LWEC Most Wanted II report (2012) identified that the supply of skilled people to conduct ecological field and laboratory research is decreasing, in part due to diminished government funding for field-based research. This means when recruiting at postdoctoral level there are often relatively few suitably qualified candidates who were trained in the UK. This is evidenced by our

experience in the College of Life & Environmental Sciences at the University of Exeter where there are currently 37 NERC-funded postdoctoral researchers, more than one-third of whom obtained their PhD outside the UK.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

Studentship training with a focus on the ecology of adaptation to environmental change offers tremendous opportunities for partnerships with business, policy and voluntary/community organisations. It is widely recognized that there are serious skills gaps in the training of postgraduates in biosciences. Indeed, the environmental sector has strongly argued for increased government support and engagement between higher education institutions and industry to deliver improved postgraduate training in ecological skills (IEEM 2011). As part of existing studentship training at the University of Exeter we have 132 active partnerships with business, policy and third sector organisations, who are providing funding and/or in-kind support to PhD studentships in environmental science. For example, DEFRA, FERA, APHA, Cefas, Environment Agency, Forestry Commission, British Antarctic Survey, Wildfowl & Wetlands Trust, Butterfly Conservation, BTO, RSPB, Songbird Trust, Zoological Society of London, Syngenta, AXA, Southwest Water, DairyCo, Shell. Thus, there is clearly an appetite for engagement with research. Further evidence of opportunities to create additional partnerships with business, policy and/or the third sector is provided by existing successful RCUK sponsored initiatives to which NERC PhD students can apply. These include the Policy Internship Scheme, which currently has seven host organisations (Parliamentary Office of Science and Technology, The Research Service; Scottish Parliament; Centre for Science & Policy; Government Office for Science; The Royal Society of Biology; The Royal Society), and the Environment YES venture designed to develop business awareness and entrepreneurship in PhD students working in environmental sciences.

How will the proposed training meet the identified demand for these skills from end-users?

To ensure that the proposed training meets the identified demand for ecological skills from end-users, we will engage with business, policy and third sector organisations to identify relevant research questions, develop studentship proposals, and promote multi-disciplinary supervisory teams that address the knowing-doing gap. Furthermore, students will undertake internships with relevant stakeholder groups, to promote knowledge exchange and develop their transferable skills. Specialist studentship training in the ecology of adaptation to environmental change, with engagement with stakeholders at its core, will directly plug skills gaps that have been identified by academia, government and industry. For example, field observation, sampling and monitoring skills, species identification, microbiology and microbial physiology, multi-disciplinary working, and translating research into practice (e.g. Knight et al. 2008; Sutcliffe & O'Reilly 2010; IEEM 2011; LWEC 2012).

What is the scientific importance of this area to the UK Environmental Research community?

Understanding the factors that will facilitate rapid adaptation to unprecedented levels of anthropogenic environmental change is likely to be the defining scientific challenge of our age. The impacts of environmental change are ubiquitous and require innovations in molecular and biological systems, ecosystems and biogeogeochemical cycles, and societal and economic systems. But what mechanisms affect invention and innovation across these biological and societal systems? Can we identify common processes that facilitate the adaptation of complex systems to environmental change? What structures set the limits of adaptation? The answers to these questions are critical to developing a research base in ecology that can provide solutions to the problems posed by rapid environmental change.

The current focus of research in this area in the UK has been to describe and document the unprecedented ecological changes that are taking place. And all too often, work is carried out at a single organizational level and on individual systems (e.g. phenological change in species X at site Y). We propose that a more focused, whole system approach is required that probes mechanisms of adaptation at multiple organizational scales contemporaneously. Such an approach recognizes the hierarchical, interconnected organization of ecological and societal systems, and seeks to identify the processes that aid rapid innovation and transformational change.

What is the UK's current capacity to deliver high quality training in this area?

The UKs current capacity to deliver high quality training in the ecology of adaptation to environmental change is extremely limited. This is due in large part to limited availability of PhD studentships in this area. Most importantly, while academic, government, and industry groups have identified a need for training in ecological field and laboratory skills (e.g. Knight et al. 2008; Sutcliffe & O'Reilly 2010; IEEM 2011; LWEC 2012), none of the existing CDTs plug this skills shortage. The 15 NERC DTPs have funding for 240 studentships annually, and at most about a third of these have a primary focus on ecological training. Exeter is part of the GW4+ DTP. In the recent studentship competition, we received ~800 applications for 28 awards. Of the allocated studentships, only about one-third went to the Living World (i.e. ecology) research theme. Thus, there is huge demand for training in this area, but limited ability to meet this need in terms of existing studentships. Furthermore, funding cuts for fieldwork mean that there is restricted ability to provide doctoral students with high quality training in ecological field skills, limiting their future employability and the UKs competitiveness in this area.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

High quality training in the ecology of adaptation to environmental change requires focused investment of the kind provided by CDTs. This investment would recognise the need for, and provide adequate resource to support training that requires research-focused fieldwork, high-tech laboratory techniques and advanced quantitative skills and a whole system approach that is interdisciplinary and multiscale. The successful NERC GW4+ DTP, of which Exeter is a partner, provides an existing infrastructure and extensive network of partnerships from which this CDT can build. Moreover, a bespoke CDT in this area of environmental change would provide a platform from which to solicit further financial and in-kind support from business, industry and third sector groups. To that end, and in order to deliver training that meets the needs of end-users, we will include relevant stakeholders on the management board of the CDT.

What would be the impact of NERC investing in a CDT in this area at this time?

A NERC CDT in the ecology of adaptation to environmental change would help position the UK as a world leader in the provision of postgraduate training in environmental science, and the development of transformative solutions to the problems of global change. Specifically, the CDT would plug several identified gaps in postgraduate skills training, including multi-disciplinarity, translating research into practice, fieldwork, and microbiology (Knight et al. 2008; Sutcliffe & O'Reilly 2010; IEEM 2011; LWEC 2012). By addressing these skills gaps, NERC would help underpin the future prosperity of the UKs environment sector.

What would be the impact of NERC not investing in a CDT in this area at this time?

Not investing in a CDT in this area at this time would mean continued under provision of skills training that is urgently required to ensure the future prosperity of the UKs environment sector.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

Literature cited: IEEM (2011). Closing the Gap: Rebuilding Ecological Skills in the 21st Century. Institute of Ecology & Environmental Management. Knight, A. T., Cowling, R. M., Rouget, M., Balmford, A., Lombard, A. T. & Campbell, B. M. (2008). Knowing but not doing: selecting priority conservation areas and the research-implementation gap. Conservation Biology 22, 610-617. LWEC (2012). Most Wanted II: Postgraduate and Professional Skills Needs in the Environment Sector. RCUK. Pfeffor, J. & Sutton, R. I. (1999). Knowing what to do is not enough: turning knowledge into action. California Management Review 42, 83-107. Sutcliffe, J. & O'Reilly, C. (2010). Ecological skills: mind the gap(s). Kew Bulletin 65, 529-538.

22. Earth System Science for Sustainable Development

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Earth System Science for Sustainable Development (ES4D) There is an urgent need to develop a new generation of students who are expert in the application of Earth System Science to real world problems connected to human well-being, such as those issues embedded in the Sustainable Development Goals (SDGs) (http://www.un.org/sustainabledevelopment/sustainable-development-goals/) and the Global Challenges Research Fund (GCRF) (http://www.rcuk.ac.uk/funding/gcrf/). We need a cohort of students who are comfortable dealing with trans-disciplinary projects, using quantitative approaches, with environment and sustainability issues at their core. PhD training is usually provided within highly specialised areas and is focussed on single environmental issues. It most often focuses on identifying problems, not providing solutions. Graduating students are not equipped with the skills required to address real world problems that combine multiple competing issues. To address this, a quantitative Earth System approach needs to be central. Examples of core training courses for the cohort include: Systems modelling skills. The Sustainable Development Goals. The Earth System and its connectivity. Mechanisms of environmental policy making. Communicating Earth system thinking in the boardroom. Examples of specific training courses on hot topics are: Early warning systems for environmental tipping points. Robust social-ecological systems design.
Please evidence the training need in this area from business, policy and/or third sector users.
This training need comes from three related directions: 1. The need for Earth System Scientists to inform Sustainable Development: Achieving the Sustainable Development Goals (SDGs) requires a new generation of Earth System scientists versed in the challenges of sustainable development, and equally a new generation of development scientists versed in the Earth System. ES4D would bridge these gaps to provide the much needed environmental science to support sustainable development. 2. The need for Earth-System-educated policymakers: The connected nature of the Earth System means that environmental policy in one realm almost invariably has consequences in other realms of the Earth System. Without Earth system thinking in policy, it is possible to end up with environmental regulations that are counterproductive overall. For example, incentives to buy and drive diesel cars were motivated by a laudable wish to mitigate climate change by reducing carbon emissions, but have had negative impacts on air quality. In contrast, by joining-up climate and air quality legislation, it would be possible to achieve co-benefits for human health, crop yields and climate change. ES4D would develop a new generation of Earth System Scientists able to apply their expertise to joined-up environmental policymaking. 3. The need for Earth System thinking in businesses: There is a growing business engagement with sustainable development and widespread enthusiasm to create a more circular economy, which applies Earth System principles of material cycling, fuelled by sustainable energy, and brings the valuation of ecosystem services into business decisions. ES4D would address a shortage of quantitatively-trained Earth systems thinkers who can transfer their skills to the private sector, to underpin these laudable aims with systems models that quantitatively assess how a more circular economy could function within the Earth system, and identify the business opportunities this opens up.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

ES4D clearly supports the goals of Future Earth (http://www.futureearth.org/), and would aim to partner with The World in 2050 project (http://www.iiasa.ac.at/web/home/research/researchProjects/TWI2050.html), with potential support from the Belmont Forum (https://www.belmontforum.org/). In the global policy sector, ES4D would look for opportunities to partner with the UN and with World Bank (http://www.worldbank.org/en/topic/sustainabledevelopment) on sustainable development. In the UK policy sector, ES4D would explore the opportunity for PhD student placements with e.g. BEIS, DEFRA, DFID, and the Committee on Climate Change. ES4D would partner with the World Business Council for Sustainable Development (http://www.wbcsd.org/) and catalyst companies such as Volans (http://volans.com/) to identify partnerships with specific businesses that could help support and offer placements and co-supervision for PhD students. Partners potentially span a wide range of business sectors (e.g. http://www.wbcsd.org/Overview/Our-members). We see particular opportunities for Earth System thinking on the circular economy to be beneficial to the chemicals sector e.g. Unilever's Sustainable Living Plan (https://www.unilever.co.uk/sustainable-living/), the construction sector e.g. Arup (http://www.arup.com/services/smart_cities), agriculture, forestry, and the retail sector e.g. Ikea People and Planet (http://www.ikea.com/gb/en/this-is-ikea/people-planet/), B&Qs One Planet Home (http://www.diy.com/one-planet-home), Marks and Spencer Plan A (http://corporate.marksandspencer.com/plan-a). We also see opportunities for systems analysis and modelling of environmental hazards, vulnerability and exposure, and the ability to integrate these to assess impact, to be beneficial to the insurance/reinsurance sector. ES4D would have many opportunities to create partnerships with NGOs concerned with sustainable development, e.g. Forum for the Future.

How will the proposed training meet the identified demand for these skills from end-users?

ES4D will develop a new generation of researchers who are comfortable straddling the current gap between Earth System Science and Sustainable Development. It will bring them together with industry, policymakers, third sector and other stakeholders to tackle shared problems - acting as a catalyst that enables translation of this research into applications that deliver tangible and sustainable social and ecological benefit. A core training element will be in systems modelling skills, focused on process-based modelling and spanning dynamical systems approaches, agent-based modelling, and application of network theory. The skills to identify and represent a complex system in a quantitative model are transferrable from the natural Earth system to social-ecological systems and human systems including the circular economy and business models for specific companies. Core training in the Sustainable Development Goals and in the Earth System and its connectivity will underpin the overarching need to take an Earth systems approach to sustainable development and associated policymaking and business initiatives. Core training in the mechanisms of environmental policy making, and in communicating Earth system thinking in the boardroom, will enable the students to engage effectively with partners from the policymaking and business sectors. Specific training in hot topics such as Early warning systems for environmental tipping points and Robust social-ecological systems design will equip PhD students to bring leading-edge methodologies into work with partners. As an example, work on tipping point early warning methods at Exeter is already being translated into commercial application in partnership with Black Swan Data Ltd.

What is the scientific importance of this area to the UK Environmental Research community?

ES4D would complement those areas of existing excellence in UK environmental science and prediction that are more focussed on the natural science of the Earth System (e.g. Met Office, CEH, NOC, BAS, NCAS, NCEO). The ES4D CDT will be distinctive in uniting a trans-disciplinary group of researchers to look beyond single environmental issues to a truly systemic view of coupled global changes in the human sphere and the biosphere. We aim to better predict global changes through understanding the interactions between the climate, natural ecosystems and human social systems. This will require advancing the state of the

art in modelling the Earth system and its component social-ecological systems. Rather than study these systems just to understand the problems they face, we will apply that understanding and modelling capability to identify transformative solutions to the global challenges faced by humankind, providing societies with an appraisal of the options to create a better future together.
What is the UK's current capacity to deliver high quality training in this area?
High quality training within specific disciplines relevant to this topic is available in many UK universities, including the University of Exeter. However, what has been lacking is the new synthesis of an Earth systems approach to sustainable development goals.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
Earth System Science for Sustainable Development (ES4D) is a new synthesis, which requires a substantive cohort of students to establish critical mass in an international context, to share methodologies, and to span the breadth of the subject matter. We need to develop a cohort of students who are comfortable thinking about trans-disciplinary problems and are confident that they have a quantitative toolkit that can be applied to a diverse range of systems problems. In other words, we need to train a generation of students who rather than seeing themselves as specialists in a particular subject area, see themselves as specialists in understanding and modelling complex systems, applied to tackling sustainable development challenges. Whilst we can already join together academic supervisors from different disciplines to co-supervise students on an ad-hoc basis, the establishment of a NERC CDT would greatly extend this and bring in co-supervision from application sectors, be they policymaking, business or third sector.
What would be the impact of NERC investing in a CDT in this area at this time?
Leading the world in producing PhDs with the capability of working on trans-disciplinary problems of sustainable development with Earth system thinking and quantitative methods at their core.
What would be the impact of NERC not investing in a CDT in this area at this time?
Continued production of highly-specialised discipline-specific PhDs who wish to remain in their own silos.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

None

23. Space Weather

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
An RFI from the Space Weather community clearly identified that physics-based disciplines are downgraded or not recruited at all in existing NERC DTP/CDTs. Our community believes this to be a glaring error in the current programme and an urgent need exists for physics-based NERC PhD students in its programme to address important environmental hazards and train future scientists with necessary skills. Space weather is driven by the Suns interaction with Earth's magnetic environment, and is a medium impact, high likelihood natural hazard in the UK National Risk Register. Potential costs are estimated as $ trillions and the Royal Academy of Engineering details each critical impact on engineered systems and infrastructure [http://www.raeng.org.uk/publications/reports/space-weather-full-report]. Understanding, modelling and predicting Space Weather and its impacts on the upper atmosphere is of paramount importance, yet our field is relatively small and we must often recruit from overseas to fill important posts in research/operations. The 2012 NERC Skills Review Most Wanted II identified the top 7 key missing skills in order; our field hits all 7. Modelling, Multi-Disciplinary, Data Management, Numeracy, Translating research into Practice, Fieldwork, Risk and Uncertainty Student training is of high importance to this NERC science. In 4 years, we have ~£10.5M of peer-reviewed NERC funding (excl. NERC Centres), yet only 4 PhD students were allocated through the DTP/CDTs in this time. This is not a lack of willing supervisors with internationally-leading projects, but a lack of knowledge in the current DTP/CDT management on how or whether Space Weather fits into the NERC remit. I understand NERC have 1200-1600 PhD students at any one time; 4 PhD students certainly counts as an urgent need for a community our size that has been marginalised in terms of access and training opportunities for the next generation of highly numerate space weather students and researchers.
Please evidence the training need in this area from business, policy and/or third sector users.
The National Risk Register identifies that extreme Space Weather can result in severe impacts that have governmental policy implications. The government's plan incorporates significant work to better understand and plan for extreme space weather events. Investigations continue into the resilience of each of the nine critical infrastructure sectors, and the Met Office Space Weather Operations Centre (MOSWOC) has been created to provide forecasts and critical information necessary to support the technology on which our 21st Century lives depend. The Met Office is now responsible for space weather prediction in the UK. In short, the National Risk Register spells out the need for a new cohort of scientists to improve our understanding of the likelihood of a damaging Space Weather event, the extent to which it can be forecasted and the mitigation strategies different infrastructure sectors will require. A new CDT is necessary in this field to fulfil the current training need to provide the necessary scientists that will support government and business as they plan for severe space weather events. The Royal Academy of Engineering report [http://www.raeng.org.uk/publications/reports/space-weather-full-report; Canon et al., 2013] and the National Risk Register details the wide variety of businesses that have a need to understand the effect of space weather on their ground-based, aircraft and satellite system including: the telecommunications industry, energy sector (e.g. Shell, EDF energy), infrastructure (e.g. Atkins consultancy, National Rail) and the water sector (Thames, Severn Trent, amongst others). Scientists are required to support these industries and since this is a rapidly emerging area (e.g. MOSWOC was created in 2014), a dedicated CDT is required to

fill the current training gap that has not been filled through the current DTPs/CDTs.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

Recently NERC invested Â£6M in two Highlight Topics in Space Weather, demonstrating the importance of, and their commitment to this science area. As a part of these two projects, partnerships were developed with a wide range of businesses and policy. What is missing from these Highlight Topic projects is the ability to fund PhD studentships. The Space Weather community continues to struggle to leverage any PhD studentships out of other Doctoral Training Programme or Centre for Doctoral Training on a national level with only 4 current studentships in this field. As evidence of the investment that can be leveraged out of business, the Met Office have already funded multiple independent CASE studentships in this area and have signed up to an STFC Centre for Doctoral Training in Data Intensive Science as an industrial partner. Specific ideas that the Met Office have discussed is a long placement with the Met Office, or a larger cohort of students visiting the Met Office for a shorter amount of time to perform group projects over weeks-months. These ideas seem highly appropriate for a new CDT in Space Weather, and the community will use our extensive contacts in other sectors (e.g. EDF Energy, Atkins consultancy, Thames Water etc) to demonstrate the potential for further investment in a new CDT. It should be noted that the Space Weather research community in the university sector already run many pilot research projects at undergraduate or Masters level with industry involvement, and now is the right time to increase involvement of our stakeholders in training through a formal CDT.

How will the proposed training meet the identified demand for these skills from end-users?

Proposed training will be done in consultation with the end-users. Currently, MSSL/UCL are setting up a training programme with the Met Office to understand end-user needs and identify the scientific skills required in MOSWOC. Both NERC Highlight Topic projects Space Weather Impacts on Ground Systems (SWIGS) Modelling The Acceleration, Transport And Loss Of Radiation Belt Electrons To Protect Satellites From Space Weather (Rad-Sat) have specific project partners, stakeholders and end-users involved throughout the 4-year programme. These projects provide university-based researchers the opportunity to identify the skills gap in appropriate sectors and use their partnerships with end-users to focus the correct training through the CDT.

What is the scientific importance of this area to the UK Environmental Research community?

The transfer of Earth-impacting space weather into NERCs remit (as recommended by the Wakeham report of 2008) clearly recognises its place within the environmental sciences. Space weather shares many common features with the other environmental risks catalogued in the National Risk Register, in that its causes are driven by complex natural variability, though the scale of its effects can be difficult to estimate, since they depend on the coincidence of multiple factors, each having an associated uncertainty. Although the chain of events initiating space weather processes crosses the NERC boundary to include elements of solar and heliospheric physics, the assessment of potential impacts depends very strongly on elements of NERC science. These include the configuration of the Earth's magnetic field and upper atmosphere, and the topology and geology of the Earth's surface. Because of this, evaluation and mitigation of space weather impacts also falls squarely into the NERC remit, as recognised by NERCs recent support for two Highlight Topic studies in this area (on radiation belts and geomagnetically induced currents). Some members of the space weather community in this area also sit close to the boundaries with other NERC topics, including neutral atmospheric physics, meteorology and solid-Earth geophysics. Notwithstanding this, understanding the core effects on the Earth's environment due to space weather, such as perturbations of the magnetosphere, ionosphere and radiation environment, requires a distinctively different knowledge base to other NERC topics which,

in turn, implies a distinct training need.
What is the UK's current capacity to deliver high quality training in this area?
The UK is a leading community in both the science of space weather and developing innovative new methods to understand its impact on our environment. Currently there are two annual summer-schools in the physics of Space Weather organised by the community but these courses are focussed on STFC-funded students. The summer schools primarily involve a wide-ranging, broad overview of all aspects of this discipline, rather than any deep or focussed training on the impacts of space weather, or the skills required to make operational nowcasts and forecasts. Our community is highly-skilled and more than capable of delivering high-quality training in all of the Most Wanted skills described above, including short courses on modelling, data management, numerical skills, and risks and uncertainty. What is missing is the framework with which to provide training on a more formal basis.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
NERC CDTs are strategically focussed on addressing specific skills gaps in the NERC Remit. Our discipline ticks the first seven of the Most Wanted skills boxes that are listed by NERC, and yet unfortunately there appears to be a blind spot amongst current Directors of NERC DTPs and CDTs who fail to notice that (a) our science sits squarely in the NERC science remit and (b) our project plans specifically address the Most Wanted skills. A CDT is the appropriate format for delivering this training as it will formalise the training opportunities in our field into a common national programme, galvanising the community towards providing a clear and targeted training of NERC PhD students. By bringing together a critical mass of talented Space Weather scientists, we can deliver the required cohort of scientists with not only the highly numerate, multi-disciplinary, statistical and modelling skills required in general in the UK, but also with essential Space Weather knowledge and experience to support government and industry, as identified above.
What would be the impact of NERC investing in a CDT in this area at this time?
A NERC investment would provide the necessary scientists required as the field of Space Weather expands. We need new researchers, new operational forecasters, and Space Weather experts to work in the energy, engineering infrastructure and telecommunications sectors. As mentioned above, although the UK have pioneered much of the science behind space weather, we do not have the trained workforce necessary for new roles in MOSWOC, in government, and in industry. Targeted investment now will ensure that UK has the right expertise to plan for and mitigate the challenges posed by extreme space weather hazards.
What would be the impact of NERC not investing in a CDT in this area at this time?
NERC have just invested Â£6M over 4 years for the community to come together and determine the impact of space weather on ground and space-based infrastructure, together with a wide range of stakeholders and end users. We currently have sufficient post-doctoral student and researchers with which to perform this research. However. The field currently supports only four NERC-funded students. As post-doctoral researchers naturally progress and move to other careers, it is inevitable that there will be holes to plug in the two large NERC projects alone, yet it is clear that there are insufficient students coming through from existing PhD infrastructure such as the DTP and current CDTs. Not investing in a CDT in this area will certainly lead to a lack of numerate, highly-skilled, multi-disciplinary researchers with the requisite knowledge to keep the UK at the forefront of Space Weather research.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

As part of MIST council and as a Reader in Space Physics at MSSL/UCL I have raised this lack of PhD opportunities with both Harriet Jevon (Associate Director, Funding Operations &

Research Careers) and Professor Duncan Wingham (Chief Executive). Harriet Jevon has acknowledged our community concerns and stated that these concerns will be folded into the consultation on the operation of the DTP and CDT programmes.

24. Minerals

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Minerals: raw materials, responsible sourcing and recycling All manufacturing and infrastructure in the UK relies on mineral resources as raw materials. These range from specialist metals for high technology applications through to aggregate supply. The sector is an important part of the UK economy and very much an international industry (e.g. www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html). This first step in the manufacturing value chain needs skilled professionals and researchers to lead and innovate in geological exploration and evaluation, and in mining and processing techniques but these functions are becoming increasingly interlinked and must also be integrated with environmental protection, social licence to operate and sustainable economic development, including linking primary supply of raw materials to recycling within the circular economy environment. The suggestion is for NERC to lead on creating a multidisciplinary Minerals CDT together with EPSRC and ESRC to enable a holistic view of raw materials supply and maximum training advantage in the CDT. The aim is to create a cohort who is strong in their disciplines, or in a particular area of interdisciplinary research, and all trained and practiced in working in multidisciplinary environments to create interdisciplinary outcomes. The NERC-led and NERC/EPSRC-funded SoS Minerals programme demonstrates how linking geological and environmental science with research normally in the engineering remit enables solutions to environmental impacts and this CDT would be more ambitious in also bringing in more socioeconomic research. This submission complements the input of the Mineral Deposits Studies Group that explains in more detail the importance and opportunity for training in the area of mineral deposit geology.
Please evidence the training need in this area from business, policy and/or third sector users.
All manufacturing needs raw materials, as does all of our buildings and transport infrastructure. Digital, clean energy and medical technologies are using a wider range of raw materials than ever before. For example, over sixty elements are needed to manufacture a mobile phone. These raw materials range from bulk aggregates, through base metals such as copper to specialist metals such as lithium, cobalt and rare earth elements. Rates of recycling vary but given the expanding population and rising standard of living, a mix of primary and recycled raw materials will be needed for the foreseeable future. Mining is important in the export earnings of developing countries and high priority as a driver of sustainable development. Some of today's essential elements (e.g. Co, Te, Se, REE) have received little research attention as ores until the critical raw materials agenda gained traction and led to the SoS Minerals programme projects that started finally in 2015. Challenges for the industry include not only a better understanding of how and where to explore for future resources (i.e. geology) but how to produce those resources by methods that are resource, energy and water-efficient and protect the environment and the workforce, whilst enhancing the well-being of the host populations at local and national level and linking to the circular economy. These are interdisciplinary challenges that combine geological and mineralogical knowledge with engineering (including bioprocessing), economic, environmental and social studies. Evidence of the importance of interdisciplinary topics comes from the SoS Minerals programme, in which the majority of part-funded associated PhDs concern processing. Most of the EU Horizon 2020 raw materials projects running in the UK centre on processing but include geology, e.g. FAME (www.fame-project.info) and

IMP@CT. It is usual for all large projects to have environmental and social work packages (e.g. HiTech AlkCarb www.carbonatites.eu).

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

This CDT topic is an opportunity to create a partnership between NERC, EPSRC and ESRC. It relates particularly to the natural resources theme of NERC, and to manufacturing industry, also to energy, in EPSRC interests. Responsible sourcing and recycling concern not only technical issues but also business models and community interactions that are within the ESRC remit. There is a well-established group of researchers in mineral deposit geology, who meet through the Mineral Deposits Studies Group and also the Applied Mineralogy Group of the Mineralogical Society and the IOM3, which also serves mining and minerals engineers. The SoS Minerals programme, co-funded by NERC and EPSRC (www.bgs.ac.uk/sosminerals, 2015-2019) involves 21 UK universities and institutions and has established that it is possible to create a multidisciplinary PhD training cohort across geological processes and minerals processing including bioprocessing. It has attracted substantial in kind, and some direct financial support from industry, with some 52 partners. Most of these are exploration and mining companies, consultants or specialist institutes. This CDT would be able to capitalise on these links and would also aim to engage more challenging partners in this sector such as NGOs. NERC and ESRC have co-funded the Resource recovery from waste programme and aspects of this can also be integrated into the Minerals CDT. Other links to the downstream supply chain of specialist manufacturers in the UK and industries who use the final products are being made, including with NERC impact accelerator grant support. There are good links to academics and companies who work on recycling, for example the University of Birmingham has just created a Centre for Strategic Elements and Critical Materials based around their recycling and chemical expertise. There are additional opportunities to create interdisciplinary partnerships with NGOs who have different perspectives on mining activity.

How will the proposed training meet the identified demand for these skills from end-users?

The training will consist of PhD research projects on specific subjects, chosen by the supervisor team and partners. The partners will be mainly from industry, including mining and exploration companies and environmental, social, minerals processing, geometallurgy consultancy companies. Most of the PhD projects are likely to be single discipline with the aim of producing early career professionals who have a solid background in their chosen discipline but can work with and innovate in an inter- and multidisciplinary environment. Some will be interdisciplinary where there are specific interdisciplinary research challenges. Industry partners will vary in size and include SMEs, for whom a PhD project could give an important boost to research and innovation activity. Industry financial contributions will be flexible in order to permit small companies to take part. By bringing in NGOs as additional partners, it will be possible to include additional aspects of raw materials supply, such as, for example, small scale mining. Whilst large-scale mining supplies the majority of the world's resources, small scale mining employs the majority of the Worlds miners and is a particularly important part of the responsible sourcing agenda. PhD topics will include mineral deposit studies and models, exploration and mining geology, geometallurgy, environmental and socioeconomic aspects, responsible sourcing and supply chains, by-products, links to recycling and re-use of waste. The CDT will include a taught component covering the whole front of the supply chain and setting this in context and integral team activities that will bring the cohort together to meet the range of stakeholders and work on challenges together. These challenge days will provide training in working in multidisciplinary environments.

What is the scientific importance of this area to the UK Environmental Research community?

Mineral deposit studies are a fundamental part of geoscience. A core of UK research is long-established and researchers publish their results in leading international journals. These results are used worldwide and involve many international industry collaborations. Other directly related fields include igneous petrology including studies of mantle volatiles, geodynamics, and structural geology. Since about 2010, the impact of the critical raw materials agenda has been to increase research in mineral deposits, with several UK universities recruiting new economic geology academics. The processing-related session in the Mineral Resources for Society theme at the Goldschmidt geochemistry conference 2017 is one of the largest in the theme, and thus provides evidence of the academic interest in applying geochemical and mineralogical skills to this area. Another session brings together minerals, energy and resource recovery. Environmental mineralogy and geochemistry is an important research topic in most UK universities. The engineering-related minerals community is much smaller in the UK but is growing, with interest from DIT in the high value potential of export earnings in this sector and research interest in big data, robotics and satellite applications. The socioeconomic community interested in minerals is difficult to define since there is no specific focus but many academics work on extractive industry issues from various points of view (e.g. anthropology, sociology, geography) and would use the research results and skills of this CDT. Devising projects for the Global Challenges Research Fund usually requires a multi-disciplinary approach, combining technical solutions with socio-economic understanding to create development impact. The skills of working with other disciplines learned in this CDT are immediately relevant here (e.g. see http://www.cornwallminingalliance.org/responsible-mining-challenges-opportunities-in-africa/).

What is the UK's current capacity to deliver high quality training in this area?

There is no CDT in this area but some of the topics are included in the remit of the NERC DTPs, others are in the EPSRC and ESRC remits for individual projects within their PhD training programmes. The SoS Minerals programme, 2015-2019 is training a cohort of 17 PhDs in geology and minerals processing aspects of raw materials (/www.bgs.ac.uk/sosminerals). Several universities have research groups working on minerals as raw materials. One of the largest is at Camborne School of Mines, University of Exeter which has 11 current PhDs in geology of ore deposits, process mineralogy and minerals processing, climate change related to the mining industry and socioeconomics, including responsible sourcing. One of these is funded through the NERC GW4+ DTP, and three through the SoS Minerals programme. The British Geological Survey collaborate with UK universities through their BUFI scheme and have a large Minerals and waste team who take part in projects in raw materials. Aspects of recycling are dealt with in some of the EPSRC materials and manufacturing doctoral training. As far as is known, responsible sourcing of raw materials is not included in any CDT activities. There is already a good basis for designing the taught component in the suite of taught MSc modules related to the minerals extractive industries run by Camborne School of Mines, University of Exeter (www.exeter.ac.uk/csm). These include coverage of environmental and social aspects, transfer courses for graduates to change specialism, and blended learning, which would include the aspects new to each candidate and complementary skills. Recent NERC early career researcher training courses and the SoS Minerals summer schools have also developed relevant teaching materials.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

A CDT format is appropriate because it would bring together the cohort in this specialist area across the country. There is no single forum in which all of the disciplines involved

would normally meet at the moment, and so creating a training cohort in a CDT would not only serve the training needs but would also encourage further multidisciplinary research on raw materials supply. A CDT format with a taught component and research on a specialist topic is ideal for this subject. The PhD project would enable in-depth research in a particular topic, either within one discipline or an interdisciplinary project. The research could be tailored to the interest of supporting partners. The taught component would introduce the students to the range topics within the CDT, reinforce knowledge in their specialist areas, include specific skills such as analytical techniques and the usual complementary skills important for early career researchers. The cohort would then carry out additional teamwork on multidisciplinary challenges, set up with supporting partners, including industry or NGO challenge days, in order to share and learn from each other's experience and gain practical experience in working together.

What would be the impact of NERC investing in a CDT in this area at this time?

Investment soon would enable the momentum gathered by the NERC SoS Minerals cohort to continue. An interdisciplinary approach would give the UK the advantage of a much more holistic understanding of raw materials. There is a distinct gap between geological and applied mineralogy skills and the manufacturing supply chain in the UK that this CDT aims to bridge. The skills developed will help establish new business opportunities in the raw materials sector downstream manufacturing including specialist high technology SMEs. This approach will produce experts in raw materials ready to take part in circular economy activities, maximising economic advantage and business opportunities that will combine issues of recycling and primary raw materials. Elsewhere, such as the Lapland Region in Finland, a business cluster already combines mining and recycling opportunities. The Outokumpu stainless steel plant at Kemi, Finland uses scrap iron and a primary supply of chromite in its manufacturing process. These kinds of approaches with mixed inputs to manufacturing are becoming routine. They are not so routine in the UK research environment though. Time and again, descriptions of research priorities ignore the importance and value of raw materials mined from the ground and concentrate on only recycling and biomaterials. Mineral resources are there for us to use, responsibly. They give access to resources that can be won with little competition against land used to grow crops. Once mined, metals can be re-used for the foreseeable future if we adopt the right manufacturing, use and recycling strategies.

What would be the impact of NERC not investing in a CDT in this area at this time?

The current SoS Minerals cohort has been a major boost to this area of research in the UK and innovative in starting new projects that combine interdisciplinary expertise in geology, mineralogy and minerals processing. Only one cohort of 17 students is being trained in this programme and the momentum will be lost as soon as this cohort is complete in 2019. NERC DTPs tend to be less accommodating of interdisciplinary projects. Individual projects will continue, funded for example by overseas student scholarships, industry and university funds as well as occasional DTP projects but these are isolated within the individual universities/university groups and miss the fundamental opportunity to create a UK group with broad and substantive knowledge of the first part of the materials and manufacturing supply chain. Research momentum and early career training in raw materials may also be lost if the UK withdraws from EU collaborative research programmes. One H2020 SC5 technical project, for example, can have the similar core funding to the whole SoS Minerals programme. Minerals: raw materials, responsible sourcing and recycling CDT would help stimulate further UK research collaboration and capacity building as well as training a valuable cohort of professionals.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

25. Laser Isotope Ratiometry

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Recent laser technology developed to explore Mars at STFC Rutherford Appleton Laboratory (see https://www.stfc.ac.uk/news/mars-technology/) has application for the analysis of gases across a wide range of environmental applications. The Laser Isotope Ratiometer uses lasers to detect very low concentrations of greenhouse gases and stable isotope composition. It can detect where traces of carbon dioxide come from in the field, for example if they originate naturally from plant respiration or through the burning of fossil fuels. Thus it could be used to determine the impact of transport on air quality and identifying sources of carbon dioxide in the environment to aid in monitoring climate change. Training in use of instrument to allow wider research community to monitor greenhouse gas emissions from e.g passing vehicle emissions.
Please evidence the training need in this area from business, policy and/or third sector users.
Department for Transport, Defra
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
Unsure
How will the proposed training meet the identified demand for these skills from end-users?
Will allow technology to be used by non-experts significantly improving upon ease of use compared to existing filed-scale equipment
What is the scientific importance of this area to the UK Environmental Research community?
It is critical the greenhouse gas emissions are accurately quantified in order to aid in monitoring of climate change.
What is the UK's current capacity to deliver high quality training in this area?
Not sure
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
N/A
What would be the impact of NERC investing in a CDT in this area at this time?
N/A
What would be the impact of NERC not investing in a CDT in this area at this time?
N/A

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

None

26. Earth Observation Technologies for Terrestrial Environment Services

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
The broad Training Priority is Earth Observation Technologies for Terrestrial Environment Services in the form of a CDT with related training offerings to DTPs (and other CDTs if relevant). The key returns from evidence of need and from surveys is that the training priority for PhDs is in Earth-observation methods with a knowledge of environmental science which would provide a step change in business/government organisations to transform their service provision. Digital skills, data science and knowledge of sensor technology are key attributes that would all be welcome. The broad outcomes would be skilled environmental scientists who can develop mathematical methods or physical technologies integrated with modern digital/informatics systems that are radical in scope and impact. A level of broad environmental science is required alongside specificity of the science targeted. Although our respondents are interested in applications such as agriculture, forestry, inland water and flooding, they also need long-term data sets with climate quality. Specific training would be: terrestrial environmental science including biodiversity, natural capital, carbon stocks and land surface processes; EO algorithm design and validation, including using statistical or numerical models; image processing with advanced mathematics such as machine learning; training in software development; programming; data mining and large-scale processing; Earth Observation instrumentation and sensors; application development fusing data sets from different sensors and domains; project management skills; solution-based problem solving. Terrestrial environment services have a broad base so students would choose from and would need to be exposed to topics with a wide range of NERC science, e.g. Biodiversity and Ecosystem Sustainability, Managing environmental change, Energy and Mineral Resources, Food Security and Sustainable Agriculture, Sustainable Urban Development, and Water Resources.
Please evidence the training need in this area from business, policy and/or third sector users.
There is increasingly substantial evidence of skills needs in environment-related data from space. The House of Commons Science and Technology 2016-176 report highlighted data analysis skills and engineering (meaning technology) related to satellites and Earth Observation (EO) in particular. Prof. Ian Boyd, Defra Chief Scientific Adviser, emphasized the need for and lack of people with the right skills. The use of EO data for environment-related applications and business development is clearly in the NERC-remit. The financial value of EO for commercial industry is high, as for EO-related policy and societal benefit. The UK Space Agencys Summary Report: Size & Health of UK Space Industry December 2016 reported Earth Observation satellite services support 4.9% of GDP (Â£89 billion). Overall space industry growth is 6.5% pa, its workforce is exceptionally highly-skilled with 75% holding at least a primary degree. In order to evidence training needs, we and our partners have been surveying companies for needs, giving us confidence in our submission. We have received inputs from agencies in the Defra family. These are very clear on the need for EO skills including knowledge of sensors, EO methods, deep IT skills and environmentally-relevant mathematics. The Belmont Forum Skills Gap Analysis supports the importance of data science in global change research. Our surveys have reported significant problems in companies sourcing EO-skilled recruits with many having to be attracted from abroad. The Institute for Environmental Analytics surveyed industry: 96% identified data analytics and 93% processing/analysing Earth Observation data as key

training needs. The Satellite Applications Catapult find skilled recruitment in the UK difficult 75% of applicants are from overseas; only 5% come from UK HEIs. The CGI group did not quantity their need but finds UK recruitment in EO areas difficult and often recruits overseas.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

There are significant opportunities in services based on terrestrial science and EO. There is a strong buy-in to this view from within industry and government. Many companies work with the NERC EO community, ranging from large companies such as Airbus (instruments and data services) and CGI Group to small companies such as Space Connexion. They have written to us expressing their need for suitably skilled students and their wish to collaborate with the NERC EO community on skills. Airbus has worked with NERC in the past on PHD programmes and has proposed a new partnership with NCEO in PhD training in EO combined with sensor technologies. The CGI Group (Consulting, IT integration and outsourcing) has expressed interest in working with NCEO to provide industrial placements of under/postgraduates. It highlights skills needs including integration of in situ data sets with EO data, enriching EO information content, use of modern Information Technologies such as cloud computing and business skills. Cloud computing companies have expressed support for EO collaborations which meet these needs. The situation is mirrored on the Institutional side. The Department for Food and Rural Affairs has established an EO Centre of Excellence which is keen to engage with NERC in development and application of EO methods for government data monitoring, regulation and policy. The Institute for Environmental Analytics at Reading University has found it needs to develop EO-related short training courses for industry to meet demands from companies such as Telespazio Vega. All these organisations have expressed interest in combining with NCEO and HEIs to support EO training. They offer CASE awards, industrial placements, a portfolio of short training courses and exposure to commercial skills, e.g. teaching project management skills in a high technology sector. We believe there would be scope for government placements too. Whilst yet to be valued, current offers appear substantial.

How will the proposed training meet the identified demand for these skills from end-users?

The key objectives are to increase substantially the flow of terrestrial science, EO knowledge and skilled postgraduates to industry and policy-orientated organisations. Both are necessary to support projected growth of this UK industry. The proposed training will, as a priority, seek to deliver training which provides key environmental science knowledge as a framework for informed development of EO methods. Through courses, online materials and fora for student researchers, the intention would be to multiply the investment benefit several times over by offering material from this CDT more widely to DTPS and relevant CDTs; EO techniques are invaluable to a range of NERC-supported projects and hence PhDs. Key aspects are to develop skilled practitioners of environmental science who are expert across EO technologies. This is a clearly identified need in our surveys in both upstream (EO instrument) and downstream (environmental service) markets. An emphasis on digital skills would provide a new skilled group of students. The benefit in the CDT is that skills development will happen during a phase where students can influence their peers over a sustained time period. They will also bring industrial and academic groups closer together having the chance to influence both and allowing new ideas to be exchanged at the informal working level. There is evidence of a demand for students who understand EO sensors. The CDT would seek to educate all students in this regard and encourage PhDs which link environmental sensor technologies to digital science. This is a necessity given the increasingly high data volume sensors of the future. Finally, the training would include practical skill development such as project management and exposure to commercial practice. So PhDs would include relevant industrial placements with industry (e.g. CGI group, Airbus, Telespazio Vega, Assimila) and government agencies e.g. Ordnance Survey, Environment Agency.

What is the scientific importance of this area to the UK Environmental Research community?

Earth Observation is an essential component of NERCs portfolio: its importance is reflected in NERC Councils support for EO-related research. A portfolio analysis in 2015 indicated there were 316 grants which included some usage of EO data corresponding to 35% of the NERC funding line. Furthermore, NERC supports the National Centre for Earth Observation) NCEO, EO in other NERC centres (notably CPOM, Comet, CEH, BAS, BGS, NCAS) and EO Research Facilities as a significant part of its national capability. National capability funding directly to EO research is approx. £5 million per year. Many NERC projects provide an integrated capability with collaborative teams integrating satellite data with in situ data and models. These give the UK a wide ranging ability to publish leading high quality science whilst providing potential to build leading roles in emerging markets such as climate services, carbon markets, and hazard information. The UK environmental research community benefits considerably from the UK governments investment of 250 million Euros over the next four years into the European Space Agency (ESA) to support research satellites and datasets that are directly relevant and exploited by NERC science (in effect our space infrastructure□). The European Space Agency in recognition of the UKs skills in environmental research located its Climate Office in Harwell, UK. NERC researchers play leading roles in many ESA satellites, providing international peer-reviewed validation of their science objectives and quality. Current missions address, for example, in the terrestrial sphere: polar and mountain ice, soil moisture and gravity fields whilst new missions will provide innovative observations of plant fluorescence and forest above-ground biomass. Many other satellites enable information on global climate data, agricultural information, land cover change etc. The value for the UK environment research community is high.

What is the UK's current capacity to deliver high quality training in this area?

The UK has consistently provided excellent quality training in Earth Observation for environmental science. Many of the experts across the world and leaders of innovative new satellite systems originated and were trained in the UK for their PhDs. There is a strong training capability in both the HEI sector and in NCEO, with good courses at undergraduate level and very good academic training knowledge at HEI level. The NERC DTPs do not seem to have taken as much advantage of this as might have been hoped to be the case. In NCEO the training capability remains strong and in fact is increasing through innovative delivery to a wide range of course participants. In HEIs, fortunately, the capability still exists and can be turned back on. NCEO has a proven track-record in delivering high quality training in Earth Observation. It had a strong PhD-training programme between 20082014 through NERC Doctoral Training Grants successfully training 29 studentships and a further 22 through research funding. Recent PhD training has been through partnerships with three NERC DTPs; through CASE awards and through NCEO staff co-supervising 10 PhD projects. NCEO co-funds four PhD students in the EPSRC CDT Maths for Planet Earth. NCEO has the capability but, through lack of PhD studentship funding, is not meeting the full demand for postgraduate training in Earth Observation skills nor does it observe the DTPs actively taking up slack. Students in HEIs who are associated with NCEO are increasingly sought after by space agencies and companies. Where NCEO and its facilities deliver Advanced Training short courses in Field Spectroscopy, data assimilation, and Earth Observation for climate modelling these courses are over-subscribed showing very good engagement at the level of individual students. Clearly there is a need to be met.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

NERC CDTs equip students with skills and training within priority areas identified by NERC and our partners, and the wider community. The training is delivered in collaboration with non-academic partners and, over the course of their studentships, individuals should have opportunities to undertake collaborative research and training with non-academic partners. The whole thrust of this submission is to propose that a CDT is appropriate because of the

demand-led nature of EO applications from industry and the skills shortages evidenced by House of Commons Committees. The industry interest is in PhDs which have a much closer alignment between environment science and commercial opportunities in a coherent fashion. NCEO has provided evidence above that industrial partners such as Airbus UK, the Satellite Applications Catapult, CGI Group and Assimila Limited have expressed interest in partnering NCEO in delivering postgraduate training and providing industrial placements as part of a doctoral training programme. The European Space Agency would also offers placements. This submission has also evidenced the willingness of new government bodies such as the Defra EO centre of Excellence to support. NERC (Business of the Environment) has identified that with Industry it will work to mitigate environmental risks and aims to develop more Strategic Partnerships. Supporting a NERC CDT in Earth Observation skills would lead to more strategic partnerships for NERC and NERC Centres. It would show that NERC is responding to the Industrial Strategy identification of Satellites and Space technology (including EO) as a priority and to the Space Growth Action Plan which was positively received in government. It will also offer NERC the opportunity of partnering with other BEIS research centres, such as the Science and Technology Facilities Council and the UK Space Agency.

What would be the impact of NERC investing in a CDT in this area at this time?

By investing in EO skills training, NERC would meet a gap identified in the UK Government Industrial Strategy and elsewhere as previously noted. It would add to the argument expressed by NERC corporately that environmental science; technology and skills are relevant to the whole economy since this CDT would seek to support companies to grow. In terms of business growth, we note that this is a critical time for EO technologies. Government views are that EO driven by environmental science can underpin services across a number of departments (cross-government service) and growth in the market place. The House of Commons Science and Technology committee wrote in bold: This crisis is already apparent in the space and satellite sector, where the need to process and analyse large amounts of data from satellites, and transform them into valuable insights, is a pivotal component of the Space Innovation and Growth Strategy. Without urgent action, data skills shortages could undermine, and potentially stall, the industries progress towards its ambitious 2030 growth target. If NERC invested at this point, then the significance of the investment would be magnified and very likely attract fresh talent to the environmental science field. The growth in services and the lack of training is currently most manifest in the terrestrial environment area where the demand for new services is most acute. Hence the NERC investment would be targeted at the most urgent priorities. For businesses and agencies that partner, then as well as fresh students the benefit will be the exposure to new research methods and skills which currently are difficult to obtain. It is very clear that the urgent need is for environmental scientists with EO skills (including sensor knowledge) and digital skills. Cloud computing companies would be prepared to align this CDT with their skills support giving gearing.

What would be the impact of NERC not investing in a CDT in this area at this time?

Evidence from industry is that they are finding it increasingly difficult to recruit Earth Observation scientists from the UK: for example we noted the difficulties of the Satellite Applications Catapult in recruiting from the UK. After Brexit it could be increasingly difficult to recruit from overseas and this will add to the need for UK training. The UK Government has invested in the European Space Agency's Earth Explorer satellite programme. After Brexit, the UK will remain a full member of the European Space Agency and have access to all its programmes, recruitment and training opportunities. Failure to invest in Earth Observation training in the UK might, however, result in potential UK students moving to Europe to fulfil their training in Earth Observation needs. It would be detrimental to NERCs desire to exploit EO data for it not to invest in a CDT which would allow it to showcase industrial benefit. It is likely that without a CDT industry will continue to struggle to interact with academia and develop new research of value to it. NERC has commissioned NCEO through National Capability funding to train new Earth Observation scientists. We find that there is a steady

set of project requests from companies which could be met by more student projects which hence we cannot satisfy at the moment. We find that HEIs cannot either. Ultimately a sustained lack of investment in a NERC CDT in EO and Terrestrial Environment Services would miss a very good opportunity to make a difference to a growing industry with intrinsic interests in environmental science.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

External documents and research used to support this evidence are: HM Government Green Paper Building our Industrial Strategy January 2017, (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/586626/building-our-industrial-strategy-green-paper.pdf) Innovate UK and Research Councils UK Industrial Strategy Challenge Fund; Engagement Workshop Briefing Pack January 2017 NERC delivery plan 2016-20 The Business of the Environment, (http://www.nerc.ac.uk/latest/publications/strategycorporate/strategy/the-business-of-the-environment/) UK Space Agency Space Innovation and Growth Strategy 2014-2030: Space Growth Action Plan, April 2014, (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/298362/igs-action-plan.pdf) UK Space Agency Summary Report The Size and Health of the UK Space Industry December 2016, (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf) House of Commons Science and Technology Committee: Third Report of 2016-17 - Satellites and Space (HC-160). Chapter 3 (Barriers to further growth) p.17-18 on Skills, (https://www.publications.parliament.uk/pa/cm201617/cmselect/cmsctech/830/830.pdf) The Belmont Forum (NERC is a partner for Action theme 4 on data-intensive environmental science) Skills Gap Analysis; e-Infrastructures and Data Management in Global Change Research, April 2017, (http://www.bfe-inf.org/sites/default/files/doc-repository/BF-Skills-Gap_Analysis-2017.pdf) Institute for Environmental Analytics Training Survey Key Results November 2016 NCEOs short skills survey, with returns from Airbus; Telespazio Vega; Space Connexions; Tessela, Satellite Applications Catapult, Defra; European Space Agency; Rutherford Appleton Laboratory (RAL Space); BEIS Science Team; the CGI Group; Assimila Limited.

27. Chemicals in the Environment

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Chemical use in the UK is growing and regulations are adopting precautionary approaches to identify hazardous chemicals (i.e. persistent, bioaccumulative and toxic). Traditional risk assessments, which incorporate exposure information, lack mechanistic insight, rely on in vivo exposure, and apply arbitrary assessment factors to assess chemical safety. Greater mechanistic insights and the application of a systems based approach would enable stakeholders to extrapolate from laboratory studies on single organisms to populations and/or communities in the field. In addition, such insights could help identify environmental hazard earlier in chemical development (saving investment on candidates that might not be approved for use) and predict potential impacts of chemical mixtures and assess interactions with other stressors on ecosystem function and ecosystem services. The use of new approaches and modelling techniques to incorporate the broader ecosystem view and improve our understanding and certainty of the impacts of chemicals on the environment, provides an opportunity to improve how chemicals are assessed. A NERC-Defra workshop, held on 20-02-17, scoped priority research questions on the management of chemicals in the environment. The output is being used to develop a Joint Strategic Research (JSR) that will address three interlinked research questions: a.What are the impacts of chemicals on populations, ecosystems and ecosystem services? b.What are the risks from chemical mixtures? c.How important are chemical stressors in relation to other stressors? Workshop attendees made a strong case for training of the next generation of ecotoxicologists, skilled in experimental, modelling and statistical techniques, to rebuild capacity for research and industry. The JSR cannot include studentships and therefore a CDT is being sought to run in parallel with the new programme to ensure capability is available for stakeholders SME, Industry, Regulatory Bodies, NGOs
Please evidence the training need in this area from business, policy and/or third sector users.
A number of leading academics have highlighted the lack of research focused on chemical stressors in the environment. Yet, several recent publications in the literature and by the European Commission have identified priority challenges facing environmental risk assessment and risk management of chemicals. The NERC-Defra workshop summarised these challenges and priorities to advance our understanding of chemicals in the environment. The UK needs to ensure its Industries (Pharmaceuticals, Consumer Goods, Plant Protection, Chemicals, Oil and Gas, Contract Research Organisations and Consultancies) continue to have access to leading academic expertise and new talent to further our understanding of chemicals in the environment and prevent adverse impacts of new and existing chemicals in the environment. Capabilities in environmental chemistry, ecotoxicology, mathematical modelling, systems biology will improve how stakeholders can prospectively assess chemicals and adopt new capabilities to transform how the community assesses chemical impacts on ecosystems in the UK and beyond. In addition, research activities could also focus on retrospective assessments supporting Regulators and the Water Industry to improve risk management tools to prioritise discharges based on ecological impact rather than chemical presence and to assess the relative environmental performance of wastewater treatment infrastructure upgrades. This would lead to a closer alignment between the scientific evidence that is routinely gathered and the protection goals of risk assessment. This would benefit regulators, chemical and other industries because it would allow prioritisation of risk, focus limited resources to design more effective monitoring

campaigns both using new capability/tools and identifying where to monitor, save money through not being over precautionary whilst identifying key drivers of risk, and would allow sustainable innovation and investment.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

A number of Industry sectors routinely invest in environmental safety research. Many of these organisations already have existing collaborative research programmes with other UK Research Councils (eg. BBSRC CTPs). They also fund research directly with UK Universities or via Trade Associations (e.g. CEFIC LRI, EFPIA). There would be opportunities to partner with Pharmaceutical organisations (e.g. AZ and GSK), Oil and Gas organisations (e.g. Shell), Consumer Goods organisations (e.g. Unilever) and Plant Protection Organisations (e.g. Syngenta and DowAgroSciences). There would also be opportunities to partner with the UK Water Industry via UKWIR or through direct links with individual water companies involved in the monitoring of chemicals in discharges and align training activities with the Chemicals Investigation Programme (CIP). In addition, the opportunity to align case awards with Policy and Regulatory organisations such as Defra, HSE, SEPA and EA would be sought. Partnerships with CROs and environmental consultancies would also be sought. A number of the organisations already support training activities via seminars and/or taught courses at Universities (e.g. Unilever run a seminar series at Birmingham and have previously held these at Lancaster University). The opportunities for CASE awards in this area would be strong but dependent on end-user (industry, policy) involvement in the design of future research.

How will the proposed training meet the identified demand for these skills from end-users?

Greater strategic involvement of end-users in the co-design of CDT studentships is needed. Historically, end-users are approached for letters of support at the last minute and have limited involvement in the design of government led research. Industry has found it difficult to engage on a project-by-project and company-by-company basis through existing DTPs. We would like to explore how CDTs management could be evolved to better involve the Industry stakeholders to ensure the capabilities being developed meet the end-users needs. The BBSRC CTP model could provide a format that better meets end-users needs. However, opportunities to modify current CDT format to get broader sector involvement in the design and management of a programme could be explored first. Many challenges faced by industry are generic in nature, often we can collaborate on environmental chemicals management in a non-competitive manner (e.g as evidenced by the CEFIC LRi programme) to help support science-based policy and provide tools to support our own chemical development programmes. The ability of regulatory agencies to use academic studies to inform policy-based decisions is dependent on the three things: 1) the relevance of the experiment to regulatory decision-making, 2) the reliability or repeatability of the experimental study, and 3) the quality reporting of data such that its relevance and reliability can be determined. Whilst most academic groups do not conduct research solely for the purpose of informing environmental risk assessments, many of these scientists do generate data that could inform regulatory decision-making. Currently many published academic studies by ecotoxicologists are compromised in nature i.e. questions raised about reliability, relevance or reporting of the data . As a result the impact of these studies can be negligible. Greater involvement of industrial and regulatory stakeholders, would raise the relevance and impact of the UK funded science in this area.

What is the scientific importance of this area to the UK Environmental Research community?

The national need for high quality science in this area is very high. This is particularly clear regarding issues such as neonicotinoid insecticides and pollinating insects, endocrine disrupters and fish populations, the safety assessment of novel substances such as nanomaterials and novel chemical formulations and how climate change, and infiltration of

marine waters into freshwater aquifers, will affect the fate and effects of environmental chemicals. The UK Water Industry are investing >Â£100M in its CIP 2 programme to collate monitoring data for a range of priority and emerging chemical pollutants. However without better ecotoxicology data (single compound, chemical mixtures and effects-based assessment endpoints) to put these monitoring data into context at the individual organism, population or catchment level inappropriate risk management or risk mitigation decisions could be made. Chemical presence is all too often associated with risk and as analytical chemical detection continues to improve (typically by 2 orders of magnitude every decade), every chemical will be found in every matrix as a result of their pseudo-persistence. Without underpinning science to inform decisions and actions to deal with these concerns, the cost to the UK economy will run into £billions (e.g. the cost to upgrade UK sewage treatment plants to remove ethinyl estradiol to 35 picrogram/l is £>30B where population level effects in fish are still uncertain). The UKs ability to influence chemicals policy in major international fora such as the European Union and the Organisation for Economic Cooperation and Development (OECD) and Strategic Approach for International Chemicals Management (SAICM) will be limited without further investment. It would be extremely beneficial if academic training of students included raising awareness of the regulatory frameworks within which industry operate.

What is the UK's current capacity to deliver high quality training in this area?

A number of research institutes in the UK are active in this area of research (e.g. Brunel, Plymouth, Exeter, York, Lancaster, Birmingham). However, there has been no major programme on chemicals in the environment since 1992 (HSAC DEFRA, personal communication) and Post-doctoral talent in the UK is limited. There is an urgent need to address this and ensure the talent pipeline and expertise in the UK is secure to address the pressing environmental questions and protect our ecosystems for future generations.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

A NERC CDT could help rebuild the talent pipeline in the UK and ensure new approaches are incorporated into future decision making (both regulatory and product innovation). We believe a CDT that addressed the identified priority areas would have wide sector support and the opportunity for multiple CASE awards from chemical (pharmaceutical, agrochemical, oil, consumer goods companies) and water organisations. An opportunity to connect academic partners with a broad community that spanned multiple multinational organisations and support organisations (SMEs, consultancies, and contract research organisations), and regulatory and policy stakeholders is readily achievable.

What would be the impact of NERC investing in a CDT in this area at this time?

A NERC CDT in this area would ensure the UK continues to support our academic community to foster and nurture the future talent to feed and support our industries and regulatory communities. Many of our organisations are reliant on access to this talent to ensure new innovations reach the market (in the UK and beyond), comply with global and regional regulations and ensure chemicals we use in our activities do not impact our ecosystems. This CDT would enable UK based organisations to maintain and build strong partnerships with UK academics and help leverage these outputs to support UK and Global partnerships and activities. Such a CDT would enable the UK to partner and lead on addressing priority challenges that have been identified in the NERC-DEFRA workshop and incorporate new scientific advances into how our community assesses chemical risks and impacts.

What would be the impact of NERC not investing in a CDT in this area at this time?

The next generation of talent (academics, industry and regulatory scientists) will not be developed and the current UK academics will have limited resource to contribute to priority challenges. The UK academic population will continue to fade, potentially not recovering, and will be unable to contribute to evolving how chemicals in the environment are assessed. UK-based businesses will be reliant on expertise from outside the UK to inform safety and

compliance with existing and evolving regulation/legislation around the world.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

28. Environmental Fluid Flows with Complex Rheologies

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
There are many examples of environmental fluid flows with complex rheologies - arising from thermodynamic effects (lava, mushy ice), particles (land slides and debris flows, avalanches or fluvial and coastal transport) or bubbles (sequestration of CO2, limnic eruptions and the release of gas hydrates). These are flows that could be natural hazards, hazards to subsea infrastructure, meteorological or oceanographic processes, or flows from which energy can be generated. Modelling large-scale environmental flows is becoming increasingly driven by Big Data, relying on huge databases of observations to infer future outcomes. There is a pressing need to revisit mathematical and physical modelling in light of this, to make predictions for situations where data does not exist because the climate is changing or because we are exploring beyond anything we have before. Mathematical and physical modelling is also needed to make our Big Data approaches both more intelligent and efficient. This complex fluids CDT would focus on three threads of challenges unique to environmental flows. The development of simplified mathematical models within a cohort skilled in validating and interpreting them physically. These modelling skills are essential if intelligent data-networks or efficient predictive techniques are to be developed. Smart techniques for coping numerically with complex rheology and multi-phase flow across the huge range of time and length scales found in flows in nature. Experimental design (laboratory and field), analysis methodologies and uncertainty quantification, accentuating their role in validation of numerical and mathematical threads. Each student would undertake combinations of these threads, learning from others in the cohort to understand their role in the modelling process. Because the student would be focused on the process rather than the application, they will be adaptable in the future to meet demands we do not necessarily recognise yet.
Please evidence the training need in this area from business, policy and/or third sector users.
The 2012 NERC `Most Wanted Skills Review identified modelling as the most wanted skill in the environmental sector, with multi-disciplinarity second. Fluid mechanics, ubiquitous in the environment, epitomises these skills being inherently cross-disciplinary and prerequisite to the dynamic modelling necessary for reliability and resilience assessments, forecasts of the impact of methane release at the sea-bed or feasibility studies of carbon sequestration. Two of the many areas that could benefit from the skills in modelling complex fluids in nature are the energy sector (oil and gas, sequestration and decommissioning) and natural hazards. An April 2017 report in Journal of Petroleum Technology identified decommissioning of subsea infrastructure built in the 1970s and 80s as a looming market. Approaching these difficult-to-predict projects in a way that is safe for the environment is a serious challenge that will rely on predictive modelling techniques to estimate the risk factors for e.g. sea-floor turbidities or gas leakage and the effects on ocean ecology. There is a significant and growing need to develop predictive capability of complex fluid flows within natural hazard mitigation. Historically, the effects of complex flows have been approached through expensive field-testing programmes to construct databases, which guide future operations. But this approach is not future-proof, and complementary modelling is required to permit forecasting capability. The `Insurance sector education and training authority' identified predictive modelling as key to future viability, citing the rise of automated underwriting for competitive advantage and the increase in frequency of natural and manmade catastrophic events requiring specialist skills. Munich Re, in their 2013 `Winning New Technologies

Report into the challenges of the next 50 years, also cite the need for `predictive models [of catastrophic events] that enable accurate predictions about future outcomes'.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

This complex fluids CDT is conceptualized as having broad applicability and as such has the potential to attract a wide-range of support as it matures. There is also scope for any future DTP to specialize in areas of interest derived from the broad roots of the CDT possibly by application (e.g. energy, decommissioning, natural hazards) to provide a mechanism through which the training skills developed within the CDT will be translated into future needs. The GERC (GEOEnergy Research Centre) at Nottingham University has strong links with Schlumberger and BP and the training delivered will be highly relevant to their research. Linking future DTP funding to this institute, supported by those companies would provide excellent long-term viability of the training programme and the expertise generated. Sheffield has complementary links with Shell, within the remit of fluid particle interaction and flow induced by drilling and subsea infrastructure installation. This could provide an additional mid-to-long term development of the CDT. The other key application where the rejuvenated modelling capability will be clearly applicable is in natural hazards. Long-term investment to support research after this CDT would be sought from reinsurers such as Lloyds Register (sponsor of the Risk & Reliability Engineering Group at the University of Nottingham) and AXA (sponsor of a chair in Bristol). This CDT would also provide an excellent opportunity for new collaborations to be fostered with NERC-invested centres such as BGS, FAAM, NOC, BAS whose work includes complex fluids. The development of these relationships would be important in progressing towards any future DTP.

How will the proposed training meet the identified demand for these skills from end-users?

The CDT will train students in a combination of skills fundamental to understanding complex flows in the environment. These are skills in mathematical modelling, numerical methods, laboratory and field experiment design and analysis. Crucially, student would need to undertake work across two of these areas and will be within a cohort of students developing the other complimentary techniques. The CDT will be fundamentally cross-disciplinary, at the interfaces of mathematics, science and engineering, and by ensuring that students adopt more than one technique within their course of study, any individual will develop a genuinely cross disciplinary experience. This approach will be effective by creating a coherent focal point for strategic research in the fluid mechanics community addressing the fundamental barriers to successful, ubiquitous deployment of predictive modelling of complex fluids in nature. These are, the development For example, when extracting oil and gas from below ground companies are focused on maximizing the efficiency, safety and environmental protection aspects of their operations. In an industry where mistakes can cost millions of pounds and cause vast ecological damage, understanding the complex interactions between fluids, both contained and introduced and the surrounding rock is crucial. The industry is reliant on simulations of the fluid movement and its interaction with the geology, to help deliver maximum extraction efficiency of oil and gas safely. Consequently, people with the skills to experimentally determine complex fluid behaviour in porous media and to convert that data and understanding into predictive models and numerical simulations, are in high demand. Also with the use of injected CO2 as a means of enhancing hydrocarbon recovery there is a lot of uncertainty in the science on the long-term fate of the CO2 sequestered in this way and the potential for it to undermine local rock conditions or the security of abandoned wells.

What is the scientific importance of this area to the UK Environmental Research community?

Although avalanches, limnic eruptions and gas seepage in rocks seem very different, similar approaches can be adopted when modelling their physics. The synergistic development of mathematical models with simplified experiments with numerical modelling linking through

the scales to field data is a classical approach that requires significant expertise in bridging between the disciplines. Futhermore, the underpinning equations of motion for each of these cases are similar, permitting cross-fertilization between research into apparently very different phenomena. The major gains that can be made are in developing the fundamental tools to handle multi-scale flows and skills to deliver those through the modelling process to predictive capability. The students who benefit from this training will have adaptable skills that can apply across the environmental community. The key scientific gains that can be made are in developing numerical methods to handle multi-scale flows, mathematical methods applied to new and unexplored geometries and rheologies, and experiments using novel materials to achieve similarity with environmental events.

What is the UK's current capacity to deliver high quality training in this area?

The UK is outstandingly placed to lead in this area. There is a unique history here of developing simplified fluid models that, in conjunction with experimental and field observations, can provide efficient, predictive insight or at a minimum a physical skeleton on which to base data-driven logic. However, this body of expertise is typically becoming steered more towards industrial processing applications and thus is not necessarily fully engaged in the unique challenges posed by flows on environmental scales. To solve the large-scale challenges of environmental fluid mechanics we need to instigate an approach that supports the grass-roots research to focus on those specific challenges in mathematical, numerical and experimental modelling of complex fluids in nature to drive towards step changes in application-driven research on a 5-10 year timescale. This evidence proposal is supported by environmental scientists from Nottingham (Engineering and Mathematics), Manchester (Applied Mathematics), Durham (Earth Sciences), Sheffield (Engineering), and Bristol (Earth Sciences). This is a significant body of expertise that can be coordinated to address these fundamental challenges.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

In an era where the environmental demands of 10 years' time may be very different from the demands we experience now, it is vital we equip our future scientists with versatile, adaptable skills. It is also critical that we develop scientists who are collaborative and can work together to tackle academically challenging problems. Fluids in the environment typically have complex physics, which we often don't have the complete tools to comprehensively model. Recognising the limitations of our assumptions, the validity of our approaches and their role within a wider process of understanding are critical to making progress in tackling the academic challenges environmental flows pose. This CDT recognizes the links between apparently different environmental flow, and forms a coherent basis for the fluid mechanics community to focus on the challenges that underpin all of them.

What would be the impact of NERC investing in a CDT in this area at this time?

A CDT in complex fluids with environmental applications would allow some of the UKs leading researchers in fluids and multiphase flows to refocus and rejuvenate their work into environmental applications and the challenges common to those applications. The key difference between industrial scale flows and environmental flows is typically scale, which presents its own unique challenges. There are already some excellent routes established that can lead to impact in a medium to long term, however a grass roots coordination of effort to address the significant challenges posed by fluids in an environmental context is essential for those end users to benefit from the modelling and physical understanding they need. A coherent and coordinated programme, with excellent research environment and training opportunities will also incentivise gifted students to stay in research and to develop interest in environmental science using their skills to address great challenges in this area. One of the key benefits of the proposed CDT is that scientists will not be siloed by the application of their work, but by the processes and methodologies they understand. These will be adaptable scientists who can link physical principles across disciplines.

What would be the impact of NERC not investing in a CDT in this area at this time?
There is currently outstanding research in fluid mechanics in the UK. However, the focus is not on environmental applications and there is no coherent strategy to focus and grow the ability that exists here to address the challenges posed by complex fluids in nature. If predictive modelling of processes governed by fluid flow is dominated by Big Data only, forecasting will be limited to events that have occurred in the past. This will limit our ability for exploration, our ability to deal with the most catastrophic and extreme events or to efficiently test scenarios for e.g. environmental impact of decommissioning programmes.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

29. Taxonomy and the Environment

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Climate change, land use, pollution, natural disturbance, invasive species, pests and pathogens, are factors that impact the spatial and temporal distribution of organisms, and their interactions in communities. These factors are increasing the rate of loss of organisms such as plants (Pimm and Raven 2017) and animal (including insects) species (Dirzo et al 2014). Species may disappear before they are recognized (Pimm et al 2015). Changes in the spatial and temporal distribution of organisms will bring species together to interact in new ways. This may have negative impacts and lead to the loss of species, current species communities, ecosystem function and ecosystem services. Alternatively, positive impacts and community changes may result in novel communities that drive evolution, mitigate the impact of climate change to provide necessary ecosystem functions and ecosystem services including (eg food security and water quality). The mechanisms that influence species distributions and their interactions, effect on current communities and development and future of novel communities are not well known (Wolf-Christian and Jeschke 2015). Changes in species distribution and their interactions may affect UK and international economic development, especially for ODA countries. The crucial skills required include the ability to identify species through taxonomy and DNA analysis, assess spatial and temporal distribution, measure environmental parameters, and elucidate the mechanisms of species distributions. Assess species interactions, and through models predict the impact on current ecosystems and future communities. Skills could be used to protect species, current communities and ecosystems, reduce pests, diseases and invasive species, enhance food security and promote novel communities to mitigate climate change. Through understanding the mechanisms, management options for negative impacts of species distributions and new interactions could be developed.
Please evidence the training need in this area from business, policy and/or third sector users.
Many organizations recognize the importance of species identification: Convention on biodiversity describes training in taxonomy as fundamental to the assessment of biodiversity and understanding the impact of changes to biological communities. https://www.cbd.int/gti/needs.shtml, and recognized the as a result commenced the Global taxonomy initiative https://www.cbd.int/gti/. Intergovernmental panel on climate change https://www.ipcc.ch/ recognized the impact of species moving throughout the world in response to climate change. A new bill in the USA (Plant conservation February 26, 2017) aims to improve education in plant taxonomy. Engineering and infrastructure projects need new solutions to deal with invasive species. http://www.property-care.org/trade-body-puts-invasive-weeds-giant-hogweed-and-himalayan-balsam-on-the-radar/. New global transport routes and markets after Brexit, will increase movement of invasive species, pests and diseases that will impact UK landscape and agriculture see: https://planthealthportal.defra.gov.uk/. Brexit will change regulations on the use of products for pest, disease and invasive species control. The rapid identification of organisms traps and deal with them requires new environmentally friendly products. Small businesses successfully collaborated with the tree health and plant biosecurity initiative (THAPBI https://wiki.ceh.ac.uk/display/THAPBI/THAPBI+-+Tree+Health+and+Plant+Biosecurity+Initiative) and patents have been filed. THAPBI projects have developed insect and spore traps, contributed to rapid DNA analysis technology, equipment for measurements of insect pheromones and plant stress chemicals

to detect diseases and pests. These need more field testing and further development through national and international deployment. Currently few people are able to recognize these species and have insufficient knowledge to assess the potential damage they might cause, or the outcomes from global redistribution.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

Farmers and land managers seek to maximize crop productivity in era of climate change, combat new pests and diseases and invasive species. Research may help develop new management strategies. Novel communities might lead to opportunities for bio-control in the natural environment and agriculture and recovery of ecosystem function and services in degraded landscapes. Economic activities involved in fisheries, timber and tourism need management options to deal with species in new environments. Chemical and gadget companies are also interested in agricultural pest and disease and invasive species control, and seek to develop commercial products. Several companies have collaborated with THAPBI and they perceive a large market for such products across the world. Policy makers need to be able to predict what might happen as species move and current communities are damaged, or new communities develop. Bringing together ecologists, taxonomists to collaborate with industry and policy makers will improved the technology through being able to identify organisms, understand their behaviour and find solutions. Industry and policy makers may provide in kind support or additional funding such as occurred during the THAPBI project.

How will the proposed training meet the identified demand for these skills from end-users?

There is increasing demand for the ability to identify species in order to deal with changing species distribution and new interactions among species. Training in species identification through taxonomy, and new technology such as analysing cellular components and genetics are required. Traditional taxonomic skills are being lost as people retire, species identification became old fashioned and there are fewer opportunities for experience and fewer experts to teach. Relatively new DNA methods are the only way to rapidly identify microbes and distinguish tens of thousands of species we do not know. More precision is required to identify species and the genetic relationships among species to look for species functional redundancy. These DNA methods are the only way to rapidly identify microbes and distinguish tens of thousands of species we do not know. The importance of DNA taxonomy was recognized by Tautz et al (2003). Increase capabilities in modelling the drivers of species distributions, the interactions among species and the development of novel communities with new interactions amongst species may enable us to deal with climate change and the movement of pests and pathogens and potentially invasive species and deal with phenological mismatches resulting from climate change.

What is the scientific importance of this area to the UK Environmental Research community?

Many scientific questions concerning species interactions for specific species, with communities and ecosystems under a wide range of scenarios could be asked during a PhD. We still do not understand the drivers or mechanisms that determine current species distributions, or the ways that species interact. In particular, we still do not understand how biodiversity is maintained and ecosystem function is delivered. Under climate and land use change and the natural or human induced movement of organisms, we are unable to predict the outcome. Current species communities will be changed and new species interactions will occur. We need to understand and be able to predict the impacts, in order to successfully manage our environment. New interactions among species may drive evolutionary processes and offer mitigation methods to recover from disturbances, and improve biological control of pests and diseases. Improving our understanding of ecosystem processes and species interactions, while building the capacity of the students to deal with the increasing rate of climate change and global transportation and movement of species, is

crucial for the UK and international community.

What is the UK's current capacity to deliver high quality training in this area?

We have the capacity to deliver high quality training in species identification but this is rapidly diminishing as experienced people retire. The capacity to train people in the UK in taxonomic skills for all organisms particularly insects, cryptogams and microorganisms is particularly difficult. Few people are available that can identify microorganisms, and the development of new technology for identifying and screening vast numbers of microorganisms through biochemical means has been slow to meet science needs at an appropriate cost. Few University courses train organismal identification Edinburgh, Imperial, Queen Mary, Oxford and Cambridge Universities are among the few have developed courses that include plant taxonomy. Queen Mary University London website notes: Of critical shortage are skilled scientists in plant and fungal taxonomy, scientists that underpin much bioscience, nature conservation, plant breeding work, as well as underpinning the development of environmental policy. Kew science strategy reflects the need for taxonomists. We want a world where plants and fungi are understood, valued and conserved - because our lives depend on them. Short taxonomy courses run by such organizations such as BSBI, Field studies council, SNH Natural England etc are excellent but are often insufficient to develop real skill that is sustainable. Species identification activities often rely upon volunteers. Examples of available UK courses include British pest control examples of courses include:, Oxford University insect taxonomy and field sampling skills, Grasshopper and Cricket identification courses 2017. Understanding DNA and using DNA to identify species and their similarities in difference and function is proving increasingly important. UK courses appear to be for forensic analysis rather than understanding plant and animal populations. Example training courses include those at University of Central Lancaster and Kings College.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

Currently much of the training in identification skills is carried out by the voluntary sector and relies upon people self-funding. Taxonomy skills are undervalued and considered old fashioned. Species identification skills are generally seen as non-commercial although they are very useful for environmental consultancy work and environmental impact assessments. A NERC CDT program will enhance the profile of taxonomy and species identification skills as a worthwhile specialism to study. I am not aware of any current government funding for taxonomy skills. A more complete knowledge of taxonomy and methods for DNA for identification combined with ecological research questions and long term field work, will give the opportunity to learn identification skills that might be retained longer than during a short course. Students may consider such PhD programs more interesting and useful for future job prospects. The taxonomic and molecular skills identification can be used together with environmental assessments and research into function and behaviour and biochemistry to look for resilience and resistance in host organisms, and methods of control of pests and diseases A CDT program that includes participation in policy development activities for dealing with the larger picture concerning management of species distributions will encourage students to gain skills and deal with different sectors of the UK and international community.

What would be the impact of NERC investing in a CDT in this area at this time?

Currently much of the training in identification skills is carried out by the voluntary sector and relies upon people self-funding. Taxonomy skills are undervalued and considered old fashioned. Species identification skills are generally seen as non-commercial although they are very useful for environmental consultancy work and environmental impact assessments. A NERC CDT program will enhance the profile of taxonomy and species identification skills as a worthwhile specialism to study. I am not aware of any current government funding for taxonomy skills. A more complete knowledge of taxonomy and methods for DNA for identification combined with ecological research questions and long term field work, will give

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What would be the impact of NERC not investing in a CDT in this area at this time?

The number of pests, diseases and invasive species that are entering the UK and other countries is increasing. The rate of global climate change and movement of organisms through transport is also increasing. Species that change their distribution by whatever means may cause death and destruction of species and change interactions in the species communities. They may also develop novel communities that cause evolutionary change of species and develop self-regulating communities. We do not have sufficient people to identify species or their threats, nor the ability to recognize those that will cause most problems or to predict the outcomes. The UK is falling behind and other countries are becoming leaders in this area. Many more courses in taxonomy and DNA analysis techniques are becoming available outside the UK. See www.study.com for examples of many USA courses. Some courses to address this need have been developed in other countries eg from the convention on biodiversity funded by Japan and held in Canada. https://www.cbd.int/gti/doc/ntf-GTI-training-course-2016-nominees-en.pdf Global Taxonomy Initiative Training Course on Rapid Identification of Invasive Alien Species for Achieving Aichi Biodiversity Target 9, See also: International Association of Plant taxonomists http://www.iapt-taxon.org/pages/grants. In the USA a new house bill (February 26, 2017) has been introduced with the aim of improving education in plant taxonomy. Abc Taxa (http://www.abctaxa.be/) is a journal dedicated to building capacity in Taxonomy and collection management. It is the product of the Belgian National Focal Point to the Global Taxonomy Initiative This journal underlines the importance that other countries place on this issue. There is no equivalent journal in the UK. The sustainability of agricultural, tourist industries and international trade will become increasingly difficult if we are unable to manage the issues of global species movement.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

This proposed CDT arose out of an informal discussion amongst plant ecologists at Edinburgh CEH. I am submitting this on our behalf. But as this is not an official organized group I didn't claim group authority in the registration. This proposed CDT meets the needs to address environmental challenges to ecological communities and the interactions among species, in order that we can manage global change and the need to live within the earths limits. Skills in identifying species and predicting the impact of new interactions among species will enable us to contribute to the needs of the UK and also other countries, in particular ODA countries that have fewer resources. References : Dirzo et al, (2014) Defaunation in the Anthropocene, Science, , Vol. 345 pp. 401-406. Pimm and Joppa (2015) How many plant species are there, where are they and what rate are going extinct? Annams Missouri Bot Gard 100 170-176. Pimm and Raven (2017) The fate of the worlds plants. trends in Ecol and Evolution (in press) Tautz et al 2003. A plea for DNA Taxonomy, Trends in Ecology and Evolution vol 18 p 70-74 Wolf-Christian, S., Jeschke, J. (2015) Eco-evolutionary experience in novel species interactions. Ecology Letters 18 236-245

30. Human Interactions with the Environment

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
A new generation of scientists is required, capable of understanding the needs of policy, regulation and business in managing human interactions with natural processes and systems. Unprecedented climate change, population growth, and associated anthropogenic pressures on the environment will need to be managed through better systems of Governance, regulation and practice. The term Governance will be used throughout this response in the widest context and includes all aspects of policy, regulation, management and practice. Although referring to the marine environment, the underlying principles and subject below could apply to the terrestrial environment. Context / outcomes Addressing the need to develop advanced governance to tackle complex challenges of balancing increasing demands of expanding ocean economies with ecological and social protection Implementing global policy at a national level requires scientific capacity and new solutions Emerging economies need expertise in environmental Governance Socio-political context continues to evolve an investors require stable governance to encourage economic growth Brexit places further governance demands on capacity and knowledge resources across a range of environmental disciplines Knowledge needs / specific skills A CDT would offer structured skills development based on current and projected needs of public and private sector - Government, regulators, managers and practitioners Examples include: Developing credible understanding of policy development and legislative process and framework that underpins regulation Understanding natural capital and ecosystem services and how these might be applied Models as tools to inform regulation and support compliance Integrating scientific, social, political and economic evidence in decision making processes Systems approaches to environmental management Quantifying, communicating and managing risk Marine Spatial Planning Impacts of multiple anthropogenic stressors
Please evidence the training need in this area from business, policy and/or third sector users.
For the natural science community there is increasing focus on our ability to provide the knowledge and expertise required to underpin sustainable development in all its forms. As scientists, we must provide impartial, objective evidence to society to raise awareness of the natural world and the impacts that human activity has on the functioning of natural systems and processes. Government is increasingly reliant upon a combination of evidence sources, including, academia, government laboratories, agencies, commercial research organisations and NGOs to provide the expertise required to inform policy and regulation. Global policy is developing in response to anthropogenic pressures, including the UN 2030 Agenda and the Sustainable Development Goals (SDGs). At EU level, the recent Communication on International Governance (EC, 2016) sets out ambitious policy for implementing the UN Agenda, and to address the EU Integrated Maritime Policy. Marine spatial planning (MSP) is a critical tool in implementing the SDGs, improving ocean governance and achieving sustainable maritime economies. There is concern regarding capacity for planning across marine regions. Post-Brexit, there could be increased demand for regional, bottom-up governance, e.g. de-centralised energy, community-led initiatives, local ownership models etc. The scope and quality of environmental governance varies considerably between sectors countries. Globalisation adds significant complexity with some countries and businesses offsetting or negating their environmental responsibilities through third countries with less stringent environmental standards. Post Brexit there is likely to be pressure to liberalise environmental regulation to free-up the economy. Coupled to cuts in public

expenditure, we need to build on rapid advances in remote sensing, robotics, artificial intelligence, molecular science and genetics to achieve step changes in environmental understanding, monitoring and mitigation.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding

By way of example, the MASTS research community includes the majority of Scotlands marine science capacity. Our researchers organise their activities through 13 fora which include for example: fisheries, aquaculture; marine renewable energy; oil and gas; marine planning and governance and; marine stressors. Fora are closely linked to regulators, Government policy and industry bodies. Our community is becoming increasingly aware of the training and capacity requirements of these sectors. MASTS is engaged with the relevant Innovations Centres (ICs) funded by industry, the SFC and Scottish Government. The ICs related to fisheries, aquaculture, data, biotechnology, energy and sensors are all engaged in sector skills needs analysis and we are able to feed on and feed into these processes. For many sectors, negotiating environmental regulation represents a significant cost and they are keen to explore and fund new ways of minimising the costs of compliance; some of which include innovative technology, method, systems and process, development. Some sectors are actively seeking legislative change post Brexit, other are likely to follow if they foresee opportunities for more flexible regimes. Understanding the implications of such changes and developing new regulatory tools and methods are likely to be an active area of research and capacity building. The MASTS Marine Planning and Governance (MPG) Forum is supporting Scottish Government in their implementation of Marine Spatial Planning, working closely with stakeholders, including planning authorities, NGOs, etc. Central Government and Local Authorities may well support capacity building through an appropriately targeted CDT. ICs with specific environmental challenges may co-sponsor studentships. Some businesses recognise the benefits of co-sponsoring studentships, were existing staff gain further skills and qualifications or the recruited student spends productive time working within the organisation.

How will the proposed training meet the identified demand for these skills from end-users?

We are already engaged in sectors skills needs assessments either directly or through organisations with which we interact this covers the full spectrum of marine science and those sectors operating within this domain. This is an iterative process which is helping to guide the development of the MASTS Graduate School as a whole. A similar exercise could easily be conducted to include appropriate terrestrial sectors as end users. With respect to the proposed CDT training needs area identified within this document (some areas listed under Question 1), we have already identified a range of core and ancillary skills that would form the basis of a training programme within the context of a PhD. We have also explored the preferred mode of delivery of that training from an end user perspective. Where the cost-benefit favours employing those with the necessary skills, the end user is often keen to be closely involved with the process of training and skills acquisition. Where access to the necessary skills and capacity is infrequent or more specialised in nature, end users will tend to buy-in expertise as required, but still they still have a view on how that expertise needs to be delivered. The transdisciplinary nature of the proposed CDT area dictates that the training provided will need to be closely aligned with the expressed needs of potential end users. However, it is also important that the end users are, as far as possible engaged in helping to define and potentially deliver that training to PhD students. The rationale being that both parties benefit from this experience. MASTS currently operates an internship programme which offers the opportunity for members of its Graduate School to undertake periods of time during the course of their PhDs to work with Government, regulators and industry.

What is the scientific importance of this area to the UK Environmental Research community?

Applying environmental research in the context of governing, regulating and managing anthropogenic impacts on natural processes and systems, many of which are fundamental to life, is probably the most important reason for the existence of the UK environmental research community. Many of the challenges faced by those charged with mediating and regulating human interactions with the environment result from our lack of understanding of many of the complex systems and processes involved. Providing the tools, methods and data to inform and underpin decision making represents a major challenge - but also a significant and fertile opportunity for scientific advances to be made. In particular, at the interface between disciplines and with the focus that tangible research impact can be delivered.

What is the UK's current capacity to deliver high quality training in this area?

There are many academic institutions with capacity to deliver high quality training in many of the areas identified as being of use to end users. But at present, this is not co-ordinated at CDT level and is often not linked directly to end user requirements. The list of institutions provided below is not complete but provides an indication of the scope and depth of expertise within the marine science community that could be martialled to deliver a CDT in the area of environmental governance. Governance from and policy and planning perspective in the marine environment is provided by: SAMS, Plymouth, Newcastle, Hull and Dundee for example. Marine related socio-economic expertise, natural capital and ecosystem valuation expertise can be found at: Aberdeen, Plymouth Marine Laboratory and St Andrews. The marine stressors community is extensive and includes: Heriot Watt, University of West of Scotland, SAMS, St Andrews, University of the Highlands and Islands, Glasgow, Stirling, Edinburgh-Napier. Marine energy could include: Heriot Watt, Edinburgh, Aberdeen, SAMS, St Andrews, Swansea, Bangor, Plymouth, NOC. Fisheries: Strathclyde, Glasgow, St Andrews, SAMS, Bangor, University of the Highlands and Islands Aquaculture: Stirling, SAMS, St Andrews, Bangor, Swansea, Newcastle Coastal management: Glasgow, St Andrews, Edinburgh-Napier, Swansea, SAMS Deep sea: SAMS, Edinburgh, Glasgow, Newcastle, Cambridge, NOC.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

The NERC CDT format clearly acknowledges the need for PhD students to acquire a range of transferable skills relevant to future employment in their chosen discipline. The majority of PhDs will not end up working in academia and if the PhD is to remain a credible and desirable qualification, it must provide the student with skills that make them attractive to employers. From a strategic perspective, the CDT format also provides a vehicle to identify the need for future capacity requirements and a mechanism to train those needed to fulfil that capacity. With respect to the governance of the environment, the link to Policy, regulation, management and industry is patent. The need to develop human capacity to work effectively in disciplines relevant to these areas is a priority in the face of unprecedented environmental and political change.

What would be the impact of NERC investing in a CDT in this area at this time?

Globally, pressures on the natural environment are increasing dramatically as a function of climate change and population growth. From a UK perspective, the consequences of the UK leaving the European Union, has profound implications for change in environmental policy and regulation. Finding novel and cost effective methods of managing the environment or, more specifically, the effects of human interactions with natural systems and processes will become paramount. By ensuring that we actively develop a cohort of intelligent, highly trained practitioners grounded with the knowledge and skills required to help develop policy, inform and provide the tools needed for regulation and business, NERC will have made a significant national and international impact.

What would be the impact of NERC not investing in a CDT in this area at this time?

At present, NERC supports PhD studentships in the relevant disciplines but with no focused specific transferable skills training. This provision is largely uncoordinated with limited or no

interaction with the potential end users of project outputs. The students are unlikely to have had any exposure to end users who may well be potential future employers. This is an inefficient use of public funds. By failing to invest in the proposed CDT area, NERC would be failing to actively address the strategic need to build the trained capacity to meet the challenges facing those charged with managing the environment more sustainably in the face of unprecedented climatic and political changes. In a strategic context it could be argued that NERC would be failing to address capacity requirements needed to fulfil Government policy by: limiting progress towards the achievement of Strategic Development Goals and; impeding economic development where environmental regulation is limited by lack of applied knowledge or suitably qualified practitioners.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

31. Complex Observational Systems for Marine Science

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
Marine science is by its very nature international and multidisciplinary. As technology advances, allowing us to study more and more aspects of the oceans in remote locations, there is a need for scientists who have the skills to deploy and interpret complex observational systems, linking together platforms as diverse as autonomous submarines, satellites, commercials ships and floating buoys. Often these platforms form part of international activities such as ARGO, requiring networks of scientists and technologists working internationally to build systems that no country alone could develop. Training of PhD students has hitherto been specific to the specific task they face in their research, leavened with some general skills in planning and communication. There is, however, yet to be any attempt to equip the next generation of PhD students with the skills they need to design, build, exploit and extend the increasingly global nature of marine observations, spanning pole to pole and surface to abyssal sea-floor. The skills required are ones of: Systems analysis - to logically construct complex systems to address specific questions Multidisciplinary - to appreciate the bigger picture of what observational networks can achieve. Strongly numeracy - to be able to work with and blend data from disparate platforms The capability to conversing effectively with stakeholders such as Government, international bodies and IPCC. Into the future, the UK needs skilled scientists with the broad multidisciplinary skill sets that enable activities such as the designing of future ocean observing arrays, optimising ARGO deployments and designing systems for storm surge and tsunami warning.
Please evidence the training need in this area from business, policy and/or third sector users.
In May 2016 G7 Science Ministers met in Tsukuba, Japan to discuss the future of the oceans Initiative. Ministers recognised that the seas and oceans are changing rapidly, and are a crucial economic development issue. Recognising that sustained sea and ocean observations will be essential to improve knowledge about ocean climate, marine ecosystems, vulnerability to human impacts and the ways in which ocean processes affect human wellbeing, representatives from across the G7 countries recommended that Ministers take action to: 1. Support the development of a global initiative for an enhanced, global, sustained sea and ocean observing system, developing new technologies and integrating new physical, biogeochemical and biological observations. 2. Support an enhanced system of ocean assessment through the UN Regular Process for Global Reporting and Assessment of the State of the Marine Environment that would help develop a consensus view on the state of the oceans. 3. Promote the improvement of global data sharing infrastructure such as GEO/GEOSS, among others, to address the challenges. 4. Strengthen collaborative approaches to encourage the development of regional observing capabilities and knowledge networks. Through enhancement of global coordination mechanisms, infrastructure, and through training to build the capacity to better use global ocean information. 5. Promote increased G7 political cooperation to strengthen existing and enhance future routine ocean observations. The G7 Future of the Seas and Oceans initiative is now working on a 5 year plan for a collaborative next generation of observational networks. The source of this initiative makes it both high profile and international in scope. For the UK to play a leading role in this and the observational network that it develops we need our emerging scientists to be able to work effectively on an international stage, implementing complex, multidisciplinary systems.

Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage additional investment including, but not limited to, additional funding
The Global Ocean Observing System (GOOS) is designed to monitor and better understand climate change, improve weather and climate prediction, provide ocean forecasts, improve management of marine and coastal ecosystems and resources, mitigate damage from natural hazards and pollution, protect property and life on coasts and at sea and enable scientific research1. Hosted by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and co-sponsored by the World meteorology Organisation (WMO), United National Environmental Programme and the International Council for Science, GOOS provides international intergovernmental collaboration and coordination of the sustained observations of the oceans, a platform for the generation of oceanographic products and services and a forum for interaction between research, operational and user communities. Global Observing Systems are a financial and political challenge and require substantial commitment from governments. The unanimous support from the G7 Minsters demonstrates the potential of GOOS provide clear and tangible societal benefits, including serving a diverse array of users such as coastal zone managers, port managers, coastal developers, and the fisheries, tourism, oil, renewable energy, weather forecasting and insurance industries2. We envisage strong partnerships with end-users, including other CDTs, DTPs, government bodies, industry or extant observing programmes. Potential UK partners include SAMS, NOC, UEA, Liverpool, U. Plymouth, NCAS, NCEO, BAS, Marine Industries Alliance, MEDIN & RCUK Big Data Initiative. The strength of this CDT is its potential for international partnerships. Any CDT of this kind should have strong international partnership through the IOC and Partnership for Observation of the Global Oceans (POGO) networks. These will encourage training opportunities across the G7 Countries, but also capacity building within developing countries through the IOC Capacity Development programmes.
How will the proposed training meet the identified demand for these skills from end-users?
Technically, the Global Ocean Observing system is a global network of ships, buoys (fixed and drifting), subsurface floats, tide gauges and satellites that collect real time data on the physical state as well as the biogeochemical profile of the world's oceans. It comprises a measuring subsystem, a data and information management subsystem, and a subsystem for contributing to the production and diffusion of various kinds of products: measurements and forecasts of changes in water level, positions and strengths of currents, wave heights and forecasts of unusually high waves, sea ice measurements and coverage, rainfall measurements and forecasts (droughts and floods), maps and forecasts of harmful algal blooms, assessments of the vulnerability of fish stocks and farms, forecasts of likely weather- or climate-related disease. The next generation of marine scientists will require multi-skilling to work at the emerging nexus of understanding ocean processes, observational design of ephemeral processes, data telemetry infrastructure, understanding and limitations of parameter calibrations, variably scaled and quality data integration, marine data assimilation and visualisation, and smart and near-real time data product delivery. The training will involve visits both overseas and to Government depts. and funding agencies. PhD projects will tackle scientific problems requiring the student do any of: working with existing international entities, such as GOOS, to develop observation capability; to liaise and be embedded in Government depts. and agencies to address policy/legal issues associated with observations, such as gliders in territorial waters; being involved in building international teams to tackle similarly international questions. They will receive direct experience and training in internationally-coordinated marine observation.
What is the scientific importance of this area to the UK Environmental Research community?
Without the skills described above, the UK will increasingly find itself losing its leading role in marine science. In extremis we will find ourselves using observational networks purely as customers without the ability to push design and implementation of observational networks

to best meet the UKs scientific and economic needs. The scope of our science will also be affected with deep insights on global questions being tackled increasingly by countries which have the foresight to train their scientists to exploit the rapidly growing and interdisciplinary systems.
What is the UK's current capacity to deliver high quality training in this area?
To our knowledge, there is currently no coherent training programme for PhD students to develop skills in this area. Individual student may utilise global ocean observations, and as such be trained on specific aspects of the system (for instance in investigating heat uptake in the North Atlantic). But these discovery science based projects funded through DTPs, on an ad hoc basis, would not train students in relevant skills or breadth of knowledge to equip them to work within a global multidisciplinary system. POGO has developed an extensive array of training and education activities aimed at the utilisation of global ocean observing data, but these are targeted primarily at scientists from developing countries and those with economies in transition. There are ship-based training courses and fellowship programme, but none of these are aimed at PhD level training within UK.
CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.
Why is a NERC CDT the appropriate format for delivering this training?
The principles of system analysis, international collaboration and those necessary to exploit multidisciplinary data can be taught but are most effectively acquired if there is additionally a specific project to apply this to. This is because in addition to the formal training, much knowledge will be acquired by working with those already responsible for designing and maintaining the current complex global systems. This CDT addresses 8 of the 15 most wanted skills in the most recent version of the NERC/LWEC report: Modelling, Multi-disciplinarity, Data Management, Numeracy, Translating Research Into Practice, Fieldwork, Risk and Uncertainty, Sustainability Science and Planning. The proposed CDT would ensure PhD students gain skills relevant to both research excellence and todays knowledge based economy. The CDT would not cover all postgraduate training needs in environmental science, but would enhance the development of core transferrable skills and underpin research conducted through DTPs, strategic research topics and research programmes.
What would be the impact of NERC investing in a CDT in this area at this time?
The UK will be able to capitalise on the leading role it has been and is taking globally to develop international observing networks, and of its strong role in the G7 initiative. It will provide scientists capable of recognising where gaps in complex, international observational systems prevent progress on key global questions and how these can be addressed.
What would be the impact of NERC not investing in a CDT in this area at this time?
Despite leading on the G7 initiative, the UK would find itself playing a subsidiary role in driving and developing global marine observations. This would further hinder its ability to fully exploit development of new sensors and technology, both in academia and in industry.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.

1. The Global Ocean Observing System: A summary for Policy Makers 2009/IOC/UNESCO). 2. Lindstrom et al., 2012 Framework for Ocean Observing. An integrated framework to sustained ocean observation UNESCO IOC/INF 1284.

32. Extreme Environments and Processes

Section 2: Evidence of Training Priority Submission

Training Priority – please provide a summary of the area that is being proposed as a priority for NERC training investment (Please include information concerning not only the broader training outcomes but also the specific skills training that students would receive)
The broad topic we wish to address is Extreme Environments and Processes. The area takes an interdisciplinary approach to addressing and managing environmental change, putting research at the foundation of predicting the impact of decisions and hence making planning more resilient. It includes at its core the following specialist research areas: (i) Environmental networks: conceptualisation, analysis, and application, network theory and application (ii) flood risk, coastal erosion, climate change impacts on the physical environment, water resource planning, hydrology and droughts (iii) understanding heterogeneous extreme environments: major cryospheric systems (iv) tackling the introduction of invasive species to aquatic environments (v) wildfires, and (vi) astrophysics image analysis: monitoring of the Suns activity. We need graduates who can combine in-depth environmental process understanding with strong computational skills, and who understand the societal response to extremes to produce risk-based strategies in response. The specific skills would include sophisticated computer models calibrated to satellite, airborne and ground-based observations. Students would be trained in the numerical analysis, data assimilation, data analysis, high performance computing, and programming skills needed to design, maintain and operate the current and next generation of environmental models.
Please evidence the training need in this area from business, policy and/or third sector users.
Industry and environmental managers need to be able to predict the impact of alternative decisions on complex systems (e.g., supply chains /networks, nature reserves) to minimise risk, maximise services and meet regulatory requirements. Currently, organisations face challenges in carrying out environmental forecasting activities because there are insufficient people trained to analyse the complex interactions between components of an ecosystem efficiently and to a high standard. One of NERCs own items highlights resilience to environmental hazards http://www.nerc.ac.uk/latest/publications/strategycorporate/strategy/the-business-of-the-environment/ . An example of evidence is in the latest IPCC (Church et al 2013) report which identified ice sheet dynamics, which in turn depends on ice shelf-ocean interaction and ice sheet-bed interaction, as the major uncertainty in projections of 21st century sea level rise. This uncertainty has a direct impact on infrastructure planning, for example in the design of coastal nuclear power stations (National policy statement for nuclear power generation (EN-6), Dept. of Energy and Climate Change 2012). The computing skills to be developed are widely transferable. Equations similar to those studied in glaciology apply to oceanography and weather forecasting, to hydrology, and even to quantitative trading (the Black-Scholes equation). Almost every area of human activity now employs computer programmers: modern scientific computing is a collaborative exercise that relies on a similar mix of technical and interpersonal experience. Both the technical and interpretive aspects of data assimilation the study of inverse or ill-posed problems - are also found in medical imaging and space weather monitoring. In the last decades, invasive non-native species have been associated to almost 60% of species extinctions. It is estimated that the economic cost of biological invasions in Europe is larger than â‚¬12.5 billion per year.
Please evidence the opportunities, relevant to this area of training need, to create partnerships with business, policy and/or the third sector, with potential to leverage

additional investment including, but not limited to, additional funding
Management of natural resources is a critical component of many businesses and land managers (private sector, e.g. Network Rail; and public/policy, e.g. NRW, Defra). Such stakeholders have established links with universities to conduct research and access existing mechanisms to secure funding, e.g. Innovate UK, BEIS. The Royal Society report shows societies are not resilient to extreme weather today, and their analysis indicates that the risk it poses is increasing: https://royalsociety.org/~/media/policy/projects/resilience-climate-change/resilience-executive-summary.pdf Other examples: Control of non-native species is of particular relevance for the private sector (aquaculture and water companies), which are affected by them in the daily operations. Climate change and habitat fragmentation (e.g. dams, reservoirs) have been identified as further drivers of their establishment and dispersal. The detection, control and eradication of non-native species requires a multidisciplinary training to tackle all parts from introduction, to impact assessment and eradication methods (on different aspects such as molecular methods, remote sensing, modelling, biological aspects, social perception), data and risk models are used by UK and local governments to predict flood events and to plan major infrastructure investments saving lives and minimising disruption for people, business and the economy, the UKMO UK Earth System Model UKESM has a glaciological component, the UK experiences a significant number of wildfires per year, with substantial impacts and also resource implications for the fire services. This results in a clear training need with current lack of capacity.
How will the proposed training meet the identified demand for these skills from end-users?
Training in Extreme Environments and Processes will create research scientists with the skills to conceptualise, describe, operationalize and analyse networks in a variety of systems, make accurate decisions on issues that will impact the sustainability and resilience of essential networks and environments. Students will be trained in: commonly used programming languages (C++, Python, Fortran), programming methods (e.g design patterns, testing, and revision control), parallel programming (essential for both supercomputing applications but also present and near-future personal computing devices), and the core mathematical aspects of modern scientific computing (partial differential equations, inverse problems). It would require an integrated training process ranging from the detailed technical requirements of PhD training, through short courses for professionals needing a Top-up or quick introduction to the discipline, through leadership workshops for researchers and early career professionals, to on-going network activities to build and maintain communication between academics, practitioners and end user organisations. Organisations such as the MetOffice increasingly focus their efforts on understanding the impact of extreme weather events, for which hydrological understanding is crucial. The UK has a strong international track record examining fire and work closely with the UK Fire and Rescue Service and there is a training opportunity with end-users/government organisations.
What is the scientific importance of this area to the UK Environmental Research community?
The UK scientific community has been a global leader in the science of extreme environments and processes for many decades, including for example glaciological and cryospheric research in the earths most remote and hostile environments, rapid and abrupt climate change and tipping points in the climate system, wildfires and extreme lifeforms, extreme environmental events (e.g. floods, droughts, earthquakes, volcanic eruptions), as well as species migration and invasion. The proposed theme of extreme environments and processes would therefore serve to cement the UKs role in these leading areas for the foreseeable future. Indeed, the theme is also exceptionally well suited for cross-disciplinary research, for example as increasingly sophisticated sensors and networks of sensors are being developed by physicists and engineers, and as computational engineering has been developing modelling tools that are readily transferable and highly promising in

environmental research. To assist us in managing our environment responsibly as we pursue new ways of living, doing business, escaping poverty and growing economies. Technology has advanced to allow the collection of robust data sets and this area is becoming more sophisticated. There is now a need for research that combines the analysis to define functioning ecosystems that consist of complex interacting networks.

What is the UK's current capacity to deliver high quality training in this area?

There is no existing focused, cross-disciplinary centre that engages at different interfaces and with relevant stakeholders. It is fragmented geographically and also by discipline. For example, current capacity to train students in modern glaciological modelling is somewhat disjoint. Students in Applied Mathematics, Physics, and Computer Science and Engineering will gain the necessary technical skills, but will be unused to heterogeneous environmental systems, remote sensing, and data analysis, while the opposite will be true of Earth Science and Geography students. There is a common set of training that would benefit students focussed on the various aspects of glaciology. Observational scientists need to understand the data needs of models, modellers need to appreciate the kind of observations that might be obtained and understand the models that they work with. Both groups would benefit from a compatible set of analysis tools.

CDT Specific Information – please complete if you identify this training area as suitable for CDT investment.

Why is a NERC CDT the appropriate format for delivering this training?

The proposal is within a core area of NERCs remit, being fundamentally focused on climate and climate change and environmental processes and functioning. Due to the complex levels of support required by end-users, a CDT will enable the multidisciplinary training ranging from high-end underpinning research, through creation of identity and critical mass (capacity and group building), through to knowledge exchange and training (as opposed to education). As stated above the UK has been a world leader in the science of extreme environments and processes for several decades, and training the next generation of scientists and early career researchers is a particularly appropriate and effective means of maintaining and indeed expanding on that role for many decades to come. Real future progress will increasingly be made through cross-disciplinary research and the transfer of knowledge from other scientific and engineering disciplines. Training a generation of scientists with cross-disciplinarity at the heart right from the outset of their careers is a particularly appropriate means of boosting cross-disciplinary research.

What would be the impact of NERC investing in a CDT in this area at this time?

There will be an increase in the number of trained scientists to address the consequences of continued climatic change in extreme environments. A wide ranging understanding of the impact of networks on the natural environment (and beyond) with tangible benefits to stakeholders. Individuals engaging with the training centre will develop a deep appreciation of the cross-disciplinarity of studying complex systems that underpin whole ecosystems. There is potential for huge public impact via public engagement. Helping people understand the probabilistic nature of extreme events is paramount, as is improving our ability to forecast extreme events and their wider consequences. The UK would be able to participate fully in the design of the next generation research e.g. of earth system models, either by developing independent models, or by collaborating on an equal basis with internationally based groups e.g. in the US. We propose a unique combination of academic and non-academic participants, including final stakeholders (industry and NGOs) directly affected by Extreme Environments and Processes and local governments involved in policy and regulation. By providing a multidisciplinary approach to the detection and management of a range of invasive aquaculture species, the proposed programme will contribute to enhance the UK know-how in the fight against invasive species and train the next generation of researchers working on biological invasions. Alien invasive species are a relevant problem not only for ecosystems, but also for the global economy and human health. Increasing public awareness is also crucial for their management.

What would be the impact of NERC not investing in a CDT in this area at this time?

An insufficient number of trained scientists to address the consequences of continued climatic change in extreme environments. Potentially this could lead to death and disaster. Continuing limited information base when considering impact of ecosystem management. Continued detrimental outcomes owing to unforeseen consequences arising out of complex interactive systems. Environmental sciences limited to existing reductionists concepts of specific examples and not developing an appreciation of how a complex system of networked individuals and processes create the world in which we live. Design of certain components of next generation of earth systems models could be led entirely by groups in the US, and may not be available for use by UK scientists. The ice sheet model component of the next phase of the NERC funded UKESM is only available in that context because of UK involvement in its development. The search for new approaches to adapt to the increasing environmental uncertainty in a changing world is gaining momentum very quickly. We could easily lose our European and global leadership role in e.g. flood research if such research is insufficiently supported. The strong push for postdoctoral researchers (rather than students) on NERC projects means that we have to ensure a sufficient supply of talent. Practical consequences would be that companies and government would have to look abroad for expertise and workforce given that maladaptation to climate change would come at a high societal cost. Another example is that a new list of high impact invasive species has been recently produced. It will thus be crucial to have the required expertise in place to face this problem, and the timeliness of the work proposed is therefore clear.

Any additional information (Optional): Please provide any additional information or comments concerning areas of training priority relevant to NERC's remit below.