Technologies – Theme Action Plan 3

1. Vision and scope of the theme

Using and developing technology is an essential component of NERC research and a vibrant, dynamic and innovative technology skills base is central to enabling world-class environmental science. Providing opportunities to develop and share new technological approaches across all of the NERC science disciplines is the vision of the theme.

The theme scope is for technology development of instruments, platforms, sensors and techniques used for environmental science. This also includes information and communication technology, high performance computing, e-science technologies and mathematical techniques. This theme aims to engage scientists, technologists, computer specialists and engineers working both within the NERC community and outside it, identifying that in many cases it will only be through developing new partnerships that the most effective innovations in technology can be enabled. The theme has four challenge areas where the evolution of new technologies is considered central to delivering NERC strategic goals, in addition to an overarching purpose to ensure that the UK community works with the best tools available for environmental research. Meeting these challenges requires strategically directed research, a broad portfolio of blue-sky activities and the retention of an appropriate skills-base. The strategic technology challenge areas from the theme report are:

- Remote sensing and earth observation,
- Intelligent field sensors and networks of sensors,
- Novel laboratory instrumentation,
- Informatics, models and data.

The technologies theme has deviated from the original theme report in one significant area, with infrastructure for environmental science now considered by the National Capability Advisory Group (NCAG) and addressed through the NC action plan. Very strong connections are required however between technology developed through Research Programmes and the evolving National Capability portfolio, since new technological approaches to observations and modelling can be expected to migrate ultimately into tomorrow's NC.

The community of scientists and engineers that are engaged with technologies-led research for the environmental sciences is very substantial[1]. National Capability within RCCs support some small teams embedded within larger application-focused research groups, providing technological resources that help to deliver research goals in the short to medium term. The HEI sector also follows this model, although there are, across all disciplines, small numbers of what might be deemed to be technology specialist research groups, where this activity is the primary focus rather than the applied use of the technology. In both RCCs and HEIs there is technologies development supported by EPSRC and STFC (and a lesser extent BBSRC) with implicit environmental application.

The common embedding of technologies research within the mainstream of NERC research makes it difficult to provide quantitative estimation of current investment levels – but an upper limit may be as high as 20% of total investment[2]. A strength arising from this embedding is that technology development is highly focused and is well informed about research needs. A weakness however has been that development has often been undertaken in relative isolation from other researchers in similar fields, or in isolation from other Research Councils and industry. There have been some historic weaknesses in supporting more speculative technologies research that has a medium to long-term outlook. These are high priority issues for the theme to address.

[1] Data from the Proof of Concept research programmes indicates in excess of 150 active research groups.
[2] NERC Technology Management Plan pp 4. Published 2007

Creating new external partnerships is an essential component of the theme strategy. In most cases what are termed new technologies for environmental science are really translations of existing technology into new application areas. Promoting such partnerships requires the environmental science community to work with external researchers, for NERC to create new collaborative opportunities with other organisations in the UK and overseas, and develop a supportive structure that enables innovation in conjunction with commercial partners. Technologies activity provides in practice one of the most ready interfaces for engagement with external organisations. The theme operates at the scientific margins of other Research Councils (in particular STFC, EPSRC and BBSRC), and is concerned with technology of interest across Government (e.g in Defra, DECC, MoD), in agencies (e.g. EA, Met Office, DSTL etc), and to commercial organisations.

2. Five-year view of the theme 2010-2015.

The breadth of topics that are encompassed by the technologies theme is very great and these underpin virtually all areas of environmental science. The strategic goal of the theme is to support a research environment in the UK that allows innovative environmental research tools to emerge in a timely way across all the theme challenge areas.

Delivering this strategic goal requires more than just directed research programmes. Achieving the theme goals requires also cultural changes in the perception and valuing of technologies research for environmental science and this will be a key challenge over the next five-year period. The approach to engendering a change in the positioning of Technologies requires the use of broad range of tools. TAP1 recommended changes to the peer review process in responsive mode and created a broad ranging opportunity associated with proof of concept research. TAP 2 and TAP 3 have focused high profile and high impact directed investments in particular technology challenge areas. These have included the major networks of sensors research programme for technology demonstration, and collaborations with the Royal Society of Chemistry on training in analytical science and with NASA developing new technology for high altitude unmanned platforms. In addition there have investments where new technology development is embedded within research programmes led by other themes, including Next Generation Weather and Climate Modelling, Macronutrient Cycles, Ocean Shelf Edge Exchange Processes and in Human Modified Tropical Forests.

Whilst the strategic goal of the theme will remain unchanged over the next five years, the approach will certainly evolve. The direction of travel is for greater embedding of a technology development framework within other science-led research programmes. This is likely to mean fewer stand-alone technologies activities. This is not to say however that the theme will focus only on shorter term-technology needs. Rather the approach is one that considers that even speculative new technology development, or the adoption of potentially disruptive technology, is best placed within an environment where it is closely informed by context and user needs and may be continuously tested against current state of the art. This is essential if the role of the theme as the feeder of next generation national capability is to be performed successfully. A generic five point framework for environment research technology development is laid out below. Future research programmes, jointly undertaken with other themes, will be clear about which aspects within the development framework are of highest priority.

1. Establishing technology needs and opportunities, informed by models and theory and by knowledge exchange

2. The evolution of new techniques as laboratory systems into technology that may be used in the field

3. The extension of point measurements into networked sensing systems

4. The evolution from multiple independent sensor systems to a system-of-systems approach.

5. The integration of systems information into models to test our knowledge embedded within them or to improve their performance in prediction

This evolution is mirrored in modeling technology, where needs and new numerical techniques evolve in to a model system, which in turn may be linked with other models within an Earth system modeling environment and then linked with observation data. In addition there are overarching technology requirements at all stages in this evolutionary process relating to data curation and management, the maintenance of data quality and data interoperability.

Whilst much of the vision of evolution outlined above is associated with research programmes and responsive investments, it will become increasingly important to place this activity within the context of an evolving and refreshing integrated national capability. There is a continuum of Technologies activities that spans from highly speculative proof of concept through to the development of supporting platform capability. Since there is no bright line between what is RP and what is NC we require in future TAPs, actions which can work across this spectrum. An overly narrow consideration of technology relating it either solely to research programmes or national capability may result in lost opportunities, and cross cutting and enabling technologies such as informatics, metrology, communications and automation are potentially at risk of falling between the gaps. TAP3 proposes that the Theme Leader role requires reappraisal if this improved linkage is to be achieved and the current development of an integrated NC strategy provides a further driver.

A summary of actions approved in 2008 and 2009 and their impact on the five year landscape

A summary of challenges and actions from the 2008, 2009 and 2010 Theme Action Plans, inset with focus priorities, is summarised in Table 1 at the end of this section.

2008. The 2008 TAP included a number of activities aimed at addressing gaps and weaknesses in support of blue-sky technologies research across all challenge areas and disciplines. An action addressed inconsistencies in the peer review college and moderating panel approach to Responsive Mode applications that were largely technologies-led. Since April 09, applicants have been able to identify technologies proposals at the application stage by means of an additional tick box on the JeS form. Data since this date indicates that consistently around 7% of applications choose to take the Technologies classification. Success rates relative to non-technologies proposals in some rounds have been equivalent (at 18%), and lower in others. These changes have been implemented quickly and appear to have made an important cultural impact.

A support stream for research at the Proof of Concept level was initiated in 2008 and has now run for two application cycles. This targeted a particular gap in research associated with more speculative work developing completely new technologies or innovative translation of technologies into the environmental science domain at Technology Readiness Levels 1-4. The Proof of Concept scheme identified a very broad spectrum of research ideas: in the first funding round 30 projects from 92 in-scope applications were supported and in the second round 26 projects from 70 applications, making a total investment of £6.2M. This large diverse portfolio of basic research will be monitored in 2011 and 12 as projects complete and appropriate mechanisms for succession support, and scheme continuation will be considered.

2009. The prioritization for 2009 was the design of two high profile and high impact actions that addressed significant gaps in the current portfolio and in particular where those gaps impacted on more than one challenge area within the theme. The programme ‘Networks of Sensors’ was initiated to fill major gaps in research associated with sensors field trials and in demonstrating the added-value of a networked approach. The expected aim is for each project to coordinate a state-of-the-art network of field sensors to act as a pilot for the observational concept. The programme was developed with additional financial and in-kind contributions from STFC and DSTL. Six three-year projects have been prioritised out of 30 applications. The action has received very significant attention and interest from academic, government and commercial sectors and all the projects supported have a diverse range of partnerships. The action has stimulated many new links between academic developers and regulatory agencies and also with industries with interests in exploring commercial opportunities. The action has been very effective in raising general awareness of NERC investment in new technology and is one that may provide a significant KE opportunity as projects progress.

A research programme was initiated in analytical science and technology co-funded by the Analytical Chemistry Trust Fund of the Royal Society of Chemistry. This is a key technology sector for environmental science and protection[3] and is one that has constantly evolving technology and capability, driven by large global markets and commercial opportunities. Exploiting technology as it develops external to the environmental sciences community was identified as requiring directed investments in training and in building knowledge and research capacity. A programme to support a total of 28 PhDs over seven years has begun. The action has raised awareness of NERC technology activities within the RSC and has led to new connections with other learned societies interested in future training partnerships.

The theme also contributed to two cross theme actions (led by other themes) associated with next generation weather and climate modeling and macronutrient cycles. In both cases the strategic aim has been for key underpinning technology development to be conducted within a wider research programme. For the next generation modeling action, the strategic invention is focused at early stage basic technology development – level 1-2 within the framework laid out earlier. For the macronutrient action the intervention is to accelerate key measurement capabilities to be used within the observation phases of the programme itself (levels 2-3 in the development framework). Both actions provide good examples of the future direction of travel for technologies interventions, within increased focus on embedding within wider research activities.

ii) Summary of those actions proposed for 2010 (including cross theme actions)

Three research programmes are presented within TAP3 which, when taken as whole, deliver against all four of the theme challenges. A fourth action associated with restructuring of the approach to the delivery of technologies within NERC is not associated with additional costs.

T1. Next generation unmanned autonomous platforms (joint with Climate System theme)

Autonomous vehicles offer some of the most exciting technological opportunities for changing how, when and where we conduct observations. Such vehicles can operate efficiently in Earth's regions beyond human endurance – often performing tasks characterized as 'dull, dirty or dangerous'. The 2008 and 2009 Technologies TAPs identified that both aerial and submersible unmanned autonomous vehicles would play an increasingly central role for NERC in delivering instrument payloads for both short-term process studies and for long-term monitoring. A scoping study on unmanned aerial vehicles (UAVs) reported in 2009, and an opportunities review for autonomous underwater vehicles (AUVs) in 2010.

To position the UK at the forefront of unmanned platform use requires a combination of basic technology development, experimental demonstration and pro-active integration of the technology into existing and upcoming science programmes. The approaches needed to achieve a leading position differ between submersible and aerial vehicles. For the former the UK has a substantial heritage of technology development to build upon, and NERC Centres have been leading designers of underwater vehicles for environmental research. In contrast the UK has a very limited track record with unmanned aerial platforms and the research community does not have access to either medium altitude or high altitude unmanned aircraft. There are also major differences in the regulatory environment under which marine and aerial vehicles operate which moderate their usage.

An action in two parts is contained in the 2010 Technologies TAP. Part A is associated with long duration high altitude unmanned aerial vehicles, in collaboration with NASA Dryden and Ames

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[3] Frost and Sullivan 2006. Global analytical technology market approximately 36B USD pa, environmental sub-sector 3.2B USD pa.

Research Center and STFC, to study the chemical and physical properties of tropical upper troposphere lower stratosphere (UTLS) regions. Part B is a directed activity for technology development and demonstration using new AUV capability applied to the NERC ocean shelf research programme.

Both aerial and submersible actions have now been approved out of cycle and so are included here for information only.

T2. Human Modified Tropical Forests (joint with Biodiversity theme)

The loss of tropical forests has important implications for the global climate system. Deforestation is second only to the combustion of fossil fuels for energy generation as a source of GHG emissions. Converting forest into alternative land-uses (particularly agriculture) has major implications for biogeochemical cycles. The net loss of carbon to the atmosphere has been well documented, but it is also becoming clear that forest conversion alters the nitrogen and water cycles and the emission of volatile organic compounds (VOCs). Changes in emissions of biogenic VOCs impact on the generation of surface pollutants such as ozone, and may change the oxidation rate of methane in the tropics. Biosphere-atmosphere interactions remain therefore a major source of uncertainty in global climate models.

Measurements of biogeochemical exchanges in tropical forests are both people and equipment intensive and rarely cover seasonal or longer timescales. These are highly demanding environments for instruments with high temperatures and humidities, coupled with limited on-grid power or communications infrastructure. We require a step-change in experimental capability that will allow discrete biogeochemical cycles to be tracked on wider space scales and for longer time periods, and which match better to those scales associated with landscape and global change. This will be met using ambitious new miniturised approaches to low-intensity (electrical, manpower, cost etc) biogeochemical observations for parameters such as CO_2, H_2O, isoprene, aerosol fluxes, N and O_3 deposition. The concept here is for the development of new technology to be embedded within the wider programme so that it is tightly coupled to research drivers and may be tested through the programme against current state of the art. This theme contribution to the action with help generate a long-term technological legacy.

T3: Mathematics and informatics for environmental ‘omic synthesis

Rapid and ongoing advances in ‘omics technology are providing new potential for understanding the functional relationship between organisms and the environment. Thus there are opportunities to develop a detailed interpretation of the interaction between multiple levels of molecular organisation (e.g. genome, transriptome, proteome, metabolome) and organismic response to environmental change –from localised direct human modification to large-scale effects such as climate change. Historically observations and measurements have formed the scientific bottle-neck in expanding knowledge in this area. This has now changed with rapid advances in analytical capability for sequencing and for the measurements of other ‘omic properties.

There is a basic lack of fundamental knowledge about the mathematics and informatics needed to deal with unique problems in the co-synthesis of ‘omics data with other environmental parameters – the biological, chemical and physical states of ocean, land and atmosphere. This basic knowledge gap has meant that ‘omics information does not generally form part of mainstream environmental sampling. The opportunities from enhancing this synthesis of ‘omics and other datasets spans across almost all other themes, Climate, Biodiversity, EPHH, ESS, and SUNR. The action is therefore supporting the development of a long-term underpinning technological capability of major strategic importance.

The action will develop basic new knowledge of environmental informatics which can be applied to help integrate the vast amounts of data generated by ‘omics technologies with other environmental data to address the cross cutting science associated with organismic response to the environment on a molecular level. This is not just a matter of data storage and curation. The action will develop fundamental knowledge for creating novel workflow methodologies and technologies for integration of such large volumes of data into environmental analyses. A key goal is to promote development of informatics as a professional niche in order to meet the challenge posed by 'omics technologies and to ensure that the full potential of the latter is brought to bear in environmental research. This will be achieved through investment in a cohort of highly skilled researchers, brought in where appropriate from other applied fields including medicine, mathematics and biotechnology, acting as a seed for new cross-disciplinary research groups.

T4: Evolution of the Technologies theme beyond 2012.

An action is proposed to study the options for reconfiguration of Technologies as a theme within NERC. The goal is to improve the impact of the RP and RM investments through more coordinated roll out of new technologies as drivers of efficiency in National Capability. The action proposes an examination of potential structures for coordinating activity across RP, RM and NC. Such a change requires theme actions and TAPs to take a much longer-term perspective and a potential redefinition of theme role within NERC.

Table 1. Summary of Technologies theme RP.

	Theme Challenges			
	1. Earth observation and remote sensing	**2. Field sensors and networks of sensors**	**3. Novel laboratory instrumentation**	**4. Models, informatics and data**
2008 TAP Actions				
Technology Clusters	Promoting technologies across NERC disciplines			Promoting technologies across NERC disciplines
Proof of concept	Developing new technologies at TRL1-4	Developing new technologies at TRL1-4	Prioritisation of novel instrumentation for fundamental parameters	Developing new technologies at TRL1-4
Scoping studies	Remote sensing from next generation platforms	Science opportunities for demonstrator networks		
2009 TAP Actions				
Networks of sensors		Scale up of research sensors into high value demonstration networks		
Analytical science and technology		PhDs to translate new technology developments to environmental science.	PhDs to translate new technology developments to environmental science.	
Next generation weather and climate				Technologies for massively parallel computing, data assimilation and climate model initialisation
Macronutrient cycles	Regional Scale Observations	Long term low cost sensors	New tools for chemical speciation	
2010 TAP actions				
Next generation unmanned platforms	Mission science and instrumentation consortia for aerial UAVs	Mission science and sensors for sub AUVs and Autosub long-range		
Tropical forests	New techniques for biogeochemical cycle detection	Low intensity observation techniques		
Bioinformatics				Mathematical and bioinformatic tools for the synthesis of environment 'omic data
2011 and beyond				
New Data tools				Data intercomparison tools for environmental measurements and models
Proof of Concept 2	Developing new technologies at TRL1-4	Developing new technologies at TRL1-4	Developing new technologies at TRL1-4	Developing new technologies at TRL1-4
Technology for efficiency		Translation technology for autonomy and efficiency	Translation technology for autonomy and efficiency	
MEMs, microfluidics and miniturisation	Engagement with state of the art microscale manufacturing for EO	Engagement with state of the art microscale manufacturing for sensors		

iii) Science within the theme that will be developed in 2011-2014.

Section 2 (the five year view of the theme) described the strategic approach for the future and a trajectory that embeds technological research within an increasing number of applied actions developed by other science themes. These opportunities will be developed in collaboration with other theme leaders going forward. It is however possible to highlight certain key strategic technologies activities that will be placed where possible within appropriate research programmes over the next three years. The intention in most cases is not to create a stand-alone TECH action with the titles below, but rather that this activity would be undertaken in the most appropriate applied context. It is clear going forward that the theme should be much better integrated with technology for National Capability and that the technologies TAP be able to propose actions that are essentially about creating new NC technologies – e.g. similar in nature to the Climate Metrology action proposed in the 2009 and draft 2010 TAPs. The action T4 describes in more detail the needs for a better and more joined up approach between RP/RM and NC.

Data intercomparions tools: Significant efforts are directed towards the development of next generation climate, earth system and process models, comprising atmospheric, oceanic, and terrestrial sub-models. At the same time, ground- and aircraft-based *in situ* measurements as well as ground-, aircraft- and satellite-based remote sensing deliver data of unprecedented detail and accuracy. Central data storage at the NERC Data Centres and the establishment of the National Centre for Earth Observation have further supported these activities. Despite these achievements, and considerable e-Science investment, the utilization of measurement data for model evaluation and improvements within the NERC community remains hindered by both the heterogeneity of the data, and insufficiently mature tools for intercomparison. To overcome these limitations and enable the community to maximise its science output, investment is required to support the development of a data intercomparison suite, enabling community access to the archiving facilities at NERC Data Centres through a web based data portal with imaging, data extraction and scripting interfaces. This action would be integrated with the evolving NERC Information strategy.

Technology for lab efficiency: A translation programme to support the development of more automated and/or lower cost approaches to measurement science is proposed including adoption of latest sample preparation and laboratory robotics technologies. The prioritisation will be those areas where substantial efficiency gains can be achieved through investment in new technology and approaches. Technology associated with field portability and autonomy, ruggedisation, laboratory automation and automated data processing are likely to be key themes.

Continuation of Proof of concept technologies support: The 2008 TAP action to support Technologies research at the proof of concept level has proved very popular with researchers and has attracted large numbers of highly diverse and innovative technological ideas. The initial activity will draw to a close with the completion of around 60 projects in 2011. An extensive review exercise will be taken at this point to assess the outcomes and impacts of the scheme and to explore whether targeted approaches to succession projects are required. The review will draw on both academic and commercial advice. A recommendation for the potential continuation of the scheme and on succession funding for the most promising projects will be made in the 2012 TAP.

Cross-disciplinary studentships in engineering and computing: An action is anticipated in the area of cross-disciplinary studentships in engineering and computing for environmental science. Similar to the joint action with the Royal Society of Chemistry in 2009, a strategic partnership in this area is sought (potentially with EPSRC or learned society) to support new capacity in the community.

MEMS, microfluidics and miniturisation: Technologies associated with MEMS, microfluidics and miniturisation offer major potential changes in how observational environmental science is undertaken, through reductions in device size, energy consumption and manufacturing cost. The opportunities encompass both in situ sensors and EO/space instrumentation. Major investments have been made by Government to create UK manufacturing capacity and expertise in this area (e.g. the Micro and Nano Technology programme, TSB platform), but the NERC community potentially under-exploits these. Investments in new research initiatives partnering UK manufacturing capability and expertise with instrumentation engineers and environmental scientists is of long term strategic importance. Future actions would explore opportunities for new observing approaches using latest engineering and electronic technologies. It is anticipated that such an activity would be undertaken in partnership with funders such as TSB and EPSRC, and with coordinating bodies such as Centre for Earth Observation Instrumentation (CEOI).

iv) Existing major investments

Much of the research supported by NERC has some element of technological development embedded within it, but it is less common for technology development itself to be the explicit goal of particular projects or programmes. Historical data from NERC tends therefore to produce a somewhat artificially low activity count, although this problem is now largely rectified following 2009 changes to responsive mode. TAPs 2008 and 2009 provided a detailed commentary on historical activities. These investments are summarized briefly in the table below. The existence of these historical directed programmes has been taken in to account when prioritizing new activities, although in many cases a substantial period of time has elapsed since last investment when compared to the rate of technological change.

Table 2 Historical directed programme investments in technologies.

Directed programme	*Size*	*Dates*	*Challenge area*	*Examples activities*
e-Science	£15M	2001 - 2009	Informatics models and data	climate*prediction*.net, eMinerals, GODVIA, GENIE and the NERC Data Grid
Post-Genomics & Proteomics	11.7M	2003 - 2009	Novel laboratory instruments and informatics challenges	Five consortium sized grants
Oceans 2025	~10% of £120M	2007 - 2012	Networks of sensors	Autosub long-range
HIRDLS	17M	1992 - 2004	Earth Observation	
GERB	6.4M	1999-2006	Earth Observation	
Centre for Earth Observation Instrumentation (CEOI)	2.0M	2008 - 2011	Earth Observation	Co-funded by BIS and industry
Consortium Grants	~15M	2003 - 2012	Laboratory instruments, models & data, Earth Observation	ICOM, RONOCO, CAVIAR, GEOSPACE

3. Wider strategy issues

Partnerships: There are some key external partnerships associated with the 2010 TAP. The next generation platforms action provides a template for future NASA-NERC collaborative partnerships (including the next round of Earth Venture projects, due 2013) where UK and US PIs may be involved in full co-design from the outset. This collaborative model will be essential for UK scientists to gain access to the most sophisticated and technologically advanced aerial platforms in the future. The action is also likely to be collaborative with the Met Office who have complementary interests in tropical meteorology and climate. A potential partnership with EPSRC C-DIP for the bioinformatics action remains under development.

National Capability: All three research programmes proposed will provide new capability and insight into the potential architecture of environmental infrastructure in the future. All activities have an important role to play in informing how National Capability should evolve in the future and the extent to which new technology may drive up measurement and modelling quality whilst reducing costs. The 2010 TAP actions draw on a number of key existing NERC NC assets:

1) FAAM146 research aircraft to support the aerial UAV action (T1)

2) Autosub long-range to support the submersible AUV action (T1)

3) Biogeochemical measurement infrastructure at CEH, NCAS, NCEO for the tropical forests action (T2)

4) NERC Bioanalytical Facility (NBAF) to provide experimental support for the bioinformatics and biostatistics action (T3)

Training and skills: New needs are identified in the proposed action on mathematics and informatics and will be met through seeding new cross-disciplinary research groups within the environmental science community. A collaborative programme with NASA to provide training for UK scientists on UAVs platforms is being explored in addition to the joint NERC-NASA collaborative agreement on shared airborne platform access.

Economic Impact: All actions proposed by the theme have potential for substantial economic impact. The UAV action offers significant opportunity for the demonstration of new remote sensing instrumentation, with the unmanned aircraft sector considered to be primed for major expansion in the future. The tropical forest programme will make a wide-ranging contribution to understanding changes in GHG exchange as a result of human modification and may create technology capable of in situ auditing of carbon cycling for trading and verification purposes. The bioinformatics action offers the opportunity to develop commercialisable tools, and to develop better quantitative understanding of the links between molecular biology, biological variability and the capability of the biological environment to respond to change. The action may lead to better quantified assessments of chemical and physical risks to the environment including both localized and arising from global change.

Community size: The changes to the data capture in the responsive mode system and the broad scope of the proof of concept action have provided excellent measures of research vibrancy, of community size and the distribution of expertise. All NERC sectors are active in technologies, but with atmospheric science perhaps the largest and TFS the smallest. A conservative estimate is of around 150 discrete research groups in the UK with active interests and aspirations in technology development for environmental science. The capacity of the community to react to opportunities and new investment is very great. Around 100 proposals were submitted to the first proof of concept call, with a similar demand in the second round. 30 consortium proposals were submitted to the Network of Sensors actions, although funding for only 5 was available. Applications for Technologies PhD studentships outstrip supply by a factor of 8:1.

4. Theme investments

Table 3. Summary of Technologies theme investments i) awarded, ii) committed (agreed in previous TAPs but not yet awarded) or iii) requested in this TAP, plus reduced budget options.

TAP year	*Action*	*Awarded /£M*	*Committed /£M*	*Requested /£M*
2008	Proof of concept action, two funding rounds	6.2		
2008	Technology clusters in remote sensing and informatic/data	0.4		
2008	Scoping study into aerial UAVs	0.075		

2009	Networks of sensors pilot projects – six projects supported (co-funding from STFC and DSTL)	5.0		
2009	Analytical science and technology studentships (£0.8M co-funding from the ACTF of the Royal Society of Chemistry)	0.650	0.650	
2009	Next generation weather and climate prediction action (joint with Climate theme, total investment of £4M)		1.0	
2009	Macronutrient cycles action (joint actions with SUNR, EPHH, ESS, total investment of £10M)		1.0	
2010	Next generation unmanned platforms. Part B: Autonomous underwater vehicles action associated with the ocean shelf research programme		0.8	
2010	Next generation unmanned platforms. Aerial platforms to study TTL processes. (Joint with Climate and STFC, total investment of £4.6M)		3.0	
2010	Human modified tropical forests (Joint with Biodiversity theme Proposed investment £10M)			2.0
2010	Mathematics and informatics for environmental ‘omic synthesis.			4.5
	TOTALS / £M	12.3	6.45	6.5

Mathematics and informatics for environmental 'omic data synthesis
Council approved £4.5m for this action

Goals of the action.

This action will develop the fundamental knowledge needed to integrate large volumes of genomic, transcriptomic, proteomic and metabolomic data into wider environmental analyses to address new research questions. A major goal is to promote development of 'omic informatics as a professional niche within environmental research *via* discipline hopping from mathematical and computational sciences. The strategic seeding of new multidisciplinary research groups within the UK will help to realise the opportunities created by 'omics technologies and ensure that their full potential is brought to bear on current and future science challenges. These opportunities cut across many parts of the NERC remit and this action will provide underpinning knowledge in support of multiple science themes. The action will be structured to better equip NERC to more effectively respond to technology and research drivers as they emerge.

Introduction

Experimental capability to probe the genetic composition of organisms and communities, and the expression of their functions through the proteins and metabolites they produce, has developed exponentially. Sequencing technologies have reduced in cost 10,000 fold over the past decade, and it is now possible to sequence a human in a week, compared to the first which took over a decade. Similarly there have been major enhancements in proteomics and metabolomics delivered by improved separation technologies and mass spectrometer design. This explosion in capability has been driven by the bioscience and biomedical communities, but it creates unprecedented opportunities and changes fundamentally the way in which 'omics data may be obtained from, and related to, the environment.

The recent NERC omics review, which included extensive community consultation on the future roles for 'omics within the environmental sciences, identified many scientific applications[4]. For example researchers are no longer constrained to the genetic structures of only a small number of model organisms, but can now generate new data on sensitive marker species and their response to environmental challenges over the last 100,000 years, or at the whole community level, for example with soil microbes. This opens up routes to resolve key scientific uncertainties related to natural genetic variation and *biodiversity* and how this is expressed by species and communities through their environmental functions. Understanding natural variability and functional diversity has profound impacts on how the biological environment may respond to changing external *climate system* stressors such as heat, water or CO_2 in both time and space. Specifically, 'omic technologies provide a means to unravel the molecular basis of species sensitivity, plasticity and adaptation to climate change.

As yet the full potential for 'omics studies has not been harnessed in *earth system science*. These approaches should provide additional layers of detail enhancing our understanding of how living systems contribute to C and N cycle – recent genomic analyses of *Emiliania huxleyi* have provided insight into the oceanic component of global carbon regulation[5].

'Omics technologies may also be exploited to assess relationships between the *environment, pollution and health*, for example through the discovery of molecular biomarkers that are predictive of pollutant exposure in the context of monitoring and risk assessment, altering fundamentally the strategies used to determine health of species, communities and ecosystems.

Given the ability to collect genetic, transcriptional, protein and metabolic measurements routinely, it is in principle now feasible to obtain 'omics data as part of samplings conducted by the wider

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[4] NERC commissioned a review of potential options for the development and strategy for environmental omics. The full report to NERC has now been published: http://www.nerc.ac.uk/research/themes/biodiversity/events/documents/neomics-report.pdf

[5] Martinez, J.M., *et al.* (2007) *Applied and Environmental Microbiology*, **73**(2), 554-562

NERC survey, e.g. from countryside surveys, seawater CTDs, ice and sediment cores. There are also significant opportunities to re-analyse archived samples (e.g. from core stores and museums; although the extent to which there is selective loss of information over storage time remains a key challenge).

However, all of these opportunities, which span several NERC strategic priorities, share a common problem. *With massive increases in experimental capabilities have come equivalent growth rates in data volumes, such that data, and in particular the relative lack of mathematical and computational expertise to manipulate, interrogate and exploit it to its maximum, now form the major technological and scientific bottleneck.*

Description of the action

Largely irrespective of the field of investigation, there are three broad technological challenges that now hinder the delivery of the full potential of ‘omics technologies in environmental science:

1) How to mesh together different types of ’omic information (including genomics, transcriptomics, proteomics and metabolomics) as well as measurements on the whole organism (e.g. physiology) and even whole community. Data are generated using different experimental approaches in each case, and making linkage between datasets is practically and informatically complex. This is further hindered by the currently poor annotation associated with certain data types (e.g. metabolomics).
2) How to integrate and draw meaningful connections between these ‘omics data on species and communities with wider environmental conditions – that is with the physical and chemical states of soils, oceans, freshwater and atmosphere.
3) How to handle and subsequently interrogate and/or model such large-scale, complex datasets to address the specific environmental question(s) posed. Primarily this requires improved approaches for enabling a range of comparative, statistical, spatial and/or temporal analyses. In addition novel workflow methodologies and solutions for data storage and curation are needed.

This action recognises the urgent need to address the above whilst creating knowledge and technology which is scalable in nature to exploit rapidly expanding data archives. In addition, the action identifies the importance of knowledge transfer from related fields including computer science, mathematics, and bioinformatics developed in the context of the biomedical and biological sciences. **Developing and/or implementing within an environmental context a portfolio of agile informatics approaches relies heavily on skilled researchers, and increases in UK capacity have lagged far behind the rapid rise in experimental capability.**

Specifically, the action will look to create a professional niche of researchers capable of developing and using techniques which may build bridges between environmental ‘omics, biology and the physical and chemical science of Earth, focusing on fundamental questions that span many of the NERC science themes. There is no single informatics or statistical tool that will solve all problems however; combinations of network analyses, modelling approaches, and multivariate statistics will all be needed. There must be renewed efforts also to place data in their proper context through associated metadata (and relevant standards, where possible). The informatics approaches required will not be static; given the rate of technological change, flexible technologies and skills are needed which can adapt to changing data and measurements capabilities.

To achieve this will require, in part, highly skilled scientists to move between disciplines bringing with them skills developed in the synthesis and integration of data from fields such as biotechnology, biomedicine and mathematics. **The action proposes a strategic intervention to embed new scientific capability within areas of complementary expertise as the seed to grow new cross-disciplinary research groups.** In some cases this may mean co-location of new expertise with existing ‘omic experimental capability, in other cases co-location with applied environmental scientists.

Existing Investments and National Capability needs (if any).

The omics review highlighted how environmental science gains significant leverage from much larger national and international investments in ‘omics facilities. NERC invests £1.4M pa in NC at NBAF[6] / NEBC[7], a collection of analytical facilities in HEIs and a data node. The omics review recommended that this NERC investment should be maintained and developed. However this represents only a fraction of the overall ‘omics capability that is leveraged. There are ongoing NC investments at RCUK level in data curation, for example in ELIXIR[8] a project headed by the European Bioinformatics Institute[9] (EBI), part of EMBL. The historical NERC investments in creating internationally interoperable data products are again of very significant value to this action since they allow for bioinformatic technologies to exploit data beyond that generated by NERC-funded research. Data processing typically requires HPC with local data storage, and this continues to be supported using investments made in a range of HEI and RCC computer clusters. This action is focussed on the development of skills and application of tools and technologies to address new research questions. Issues relating to NERC’s investment in National Capability although linked are not part of this action.

Earlier strategic investments by NERC in the Environmental Genomics[10] and Post-Genomics and Proteomics[11] thematic programmes (£20M from 2000-2006) helped to place NERC as the international leader in the application of ‘omics technologies to the environmental sciences. This occurred during a period when data generation formed the major bottleneck. The situation has changed markedly with the advent of state-of-the-art ‘omics facilities in the UK and internationally. ***Therefore, for NERC to maintain its international leadership in this technological discipline, urgent investment is needed to increase the UK’s environmental bioinformatics expertise and capabilities to reflect the new paradigm.***

Action investments.

Since environmental science is a rather small player in the larger ‘omics technologies field, one possible option could be to do nothing. That is, to wait until other fields, like medicine, have created the basic knowledge needed to mesh ‘omics data with the environmental domain. However, the NERC ‘omics strategy indicates that a do-nothing option is likely to result in a rapid loss of UK positioning internationally, and that it is unrealistic to expect other disciplines to create optimal solutions to solve environmental research priorities. Clearly however it will be important for NERC to work closely with others to maximise potential synergies and impact whilst at the same time building its own independent capabilities. There may be broader challenges which cross RC boundaries (e.g. BBSRC/LWEC interests in food security and environmental change). The development of new environmental omics approaches is of potential interest to those agencies with statutory obligations in environmental monitoring (e.g. Defra, Devolved Administrations).

The action will support a strategic investment in up to eight new advanced research positions to act as seeds for the development of new research groupings in the UK, bridging between bioinformatics, mathematics and environmental science. The action will encourage discipline hopping from other subject areas, noting the apparent effectiveness of this strategic approach when used by EPSRC to enable long-term change in UK research capability at the mathematics/biology and physics/biology interfaces. A five-year seeding investment in people from NERC is proposed but this would require also a long-term commitment from potential host institutions, such that the sustainability of this informatics capability could be assured. The cost to NERC of each position is

[6] http://nbaf.nerc.ac.uk/
[7] http://nebc.nerc.ac.uk/
[8] http://www.elixir-europe.org/page.php - A new facility in the UK has recently been approved from the Large Facilities Capital Fund, to which NERC is a contributing partner.
[9] http://www.ebi.ac.uk/
[10] http://www.nerc.ac.uk/research/programmes/genomics/
[11] http://www.nerc.ac.uk/research/programmes/proteomics/

estimated at £100K pa (£100 x 5 yrs x 8 posts = £4M). [Note that this action does not require any capital investment.]

Following up on a key recommendation of the omics review, an investment is also required to coordinate activity nationally (£0.5M). This will include an independent advisory role on programme investments including the interface with investments made by NERC and others (e.g. other RCs). Both BBSRC and MRC were represented on the Expert Working Group that advised on the development of the omics strategy. Co-ordination and potential co-funding with the Cross-Disciplinary Interfaces Programme of EPSRC continues to be explored. A firm commitment in principle to the concept of the action may help in securing partner contributions.