Collaborative Research Priorities for the Environment Agency 2016-2020

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Environment Agency

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Introduction

The purpose of this document is to set out some of the big research questions facing the Environment Agency in delivering our duties and protecting the environment and human health. It is intended to inform external researchers and research funders about longer term priorities where we would welcome opportunities to work in partnership. While we have limited funds for research, our responsibilities make us key research users and our expertise and extensive data sets are an important research capability and resource.

Our priorities are considered under 11 interlinked themes, which are relevant to many other organisations in the Defra network and to society as a whole. Our focus is on those aspects that directly affect the Environment Agency's responsibilities but where other partners may share an interest. This is a living document, so while we expect the themes to remain relevant over a number of years, some of the questions will change and we will issue periodical updates to reflect this.

Who we are and what we do

We work to create better places for people and wildlife, and to support sustainable development.

Within England we're responsible for:

- regulating major industry and waste
- treatment of contaminated land
- river basin management and catchment planning
- water quality and water resources
- fisheries management
- conservation and ecology of water and wetland habitats
- managing the risk of flooding and coastal erosion
- helping organisations to reduce greenhouse gas emissions and adapt to climate change

Our priorities are to:

- increase the resilience of people, property and businesses to the risks of flooding and coastal erosion;
- address the causes of climate change and help people and wildlife adapt to the consequences;
- protect and improve water, land and biodiversity;
- improve the way we work as a regulator to protect people and the environment and support sustainable growth.

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Research themes

Agriculture and land use: Rising food prices, food security, population growth and other pressures are driving changes in agricultural production and land use. We need to understand changing farming practices, how soil and water resources are affected and how we can best work with farmers and other land managers to achieve sustainable growth in agriculture. We also need to understand and manage the challenging issue of diffuse urban soil and water pollution.

Energy production: The demand for alternative and secure sources of energy is creating new pressures on the environment. We need evidence on the environmental risks and management of new resources such as shale gas, renewables such as hydropower, and nuclear new build and decommissioning.

Industry and better regulation: We need to protect the environment and human health while enabling sustainable economic growth. In particular we need better ways to assess the risks from chemicals, including growing areas like nanomaterials, and to identify emission sources and their contribution to local and regional air pollution.

Waste and resources: Reuse and recycling can have knock-on environmental impacts that need to be managed to promote sustainable resource use. This requires criteria to allow materials to be recycled and wastes to be safely spread to land. Impacts from landfills remain a concern and we need to improve the assessment of methane emissions and to understand the effects of changing landfill composition.

Water supply and the water environment: Evaluating the security and resilience of water supply and managing demand is ever more important, particularly in the face of climate change. Aquifers are also vulnerable to contamination so it is vital that we understand and manage risks to groundwater resources. Improving the quality of inland and coastal waters remains a challenge and we need better knowledge of ecosystem responses to changing water quality and multiple pressures to develop sustainable catchment management. We also need to apply the latest thinking to monitor and model the environment more cost-effectively.

Research themes

Understanding flood risk: Flood and coastal erosion risk management requires us to predict and plan for environmental change and events that may not have happened before. This requires a good understanding of processes and fit for purpose data and models that span social, environmental and economic domains.

Managing flood and coastal erosion probability: Research needs to help us reduce the threat to people and property while providing wider environmental, social and economic benefits. It should support the design, construction, maintenance or adaptation of assets such as embankments, barriers and pumping stations. It should also focus on using natural features such as river channels, dunes and beaches, and take into account other pressures, for instance food security and leisure activities.

Managing the consequence of flooding: It will never be technically or economically possible to prevent flooding or coastal erosion entirely, but it is possible to manage the consequences. Research is needed into developing awareness of flood risk and establishing how this can be translated into responses to flood events through forecasting, warnings and emergency planning. We also want to build the resilience of communities and their ability to recover from events.

Climate change impacts and adaptation: The impacts of climate change remain poorly understood and adaptation is still at an early stage in many sectors. More understanding is needed of hydrohazards (floods, droughts, poor water quality and soil erosion) and their impact on people and livelihoods. We need research into effective measures to reduce the risks and the social, economic, institutional and technical barriers to adopting them.

Cross-cutting research: Economic evidence on the environmental and social effects of changes in the environment is important to support better decision-making. We also need research to help understand the attitudes and behaviours of our customers and the people we regulate to improve how we work together. And we need to evaluate the effectiveness of Environment Agency interventions to deliver our remit effectively and efficiently.

Technology and innovation: New and existing technologies have the potential to transform society's impacts on the environment, how we minimise those impacts and how we carry out our business more cost-effectively. From remote sensing to DNA analysis, from big data to the 'internet of things', we need research to help us exploit these benefits.

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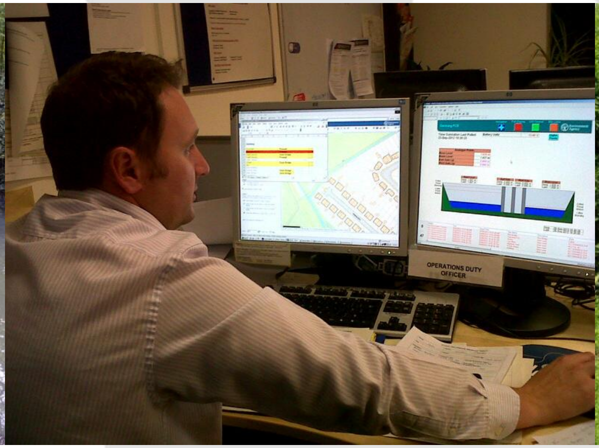
Research questions

This section outlines our long-term research questions under each theme. While not comprehensive, it provides a clear guide to our main areas of interest. The flooding issues complement the high level research priorities outlined in the LWEC Flooding Research Strategy.



Pictures: (L-R) **Environment Agency Staff monitoring pollution on River Crane** where some 3,000 fish were killed following a pollution incident on the River Crane near Twickenham. **Incident room staff** monitor river levels overnight and through a flooding incident 2012. **Bridgnorth, Shropshire: New solar powered river monitoring equipment installed on the River Severn.** The new station uses modern sensors which are both more accurate and reliable, and solar power to run the station making it both more resilient and environmentally friendly.

Agriculture and land use

What are the levels of chemicals in rural soils? The Soil and Herbage Survey in 2007 measured levels of common potentially toxic elements (PTEs) and some persistent organic pollutants (POPs) in rural soils. We would like further work to assess changes in soil contaminants including novel substances such as nanoparticles (e.g. silver or cerium dioxide), perfluoro alkyl compounds, pharmaceuticals, veterinary medicines, pesticides and flame retardants. This is important to provide baseline data to assess the impact of material applications such as recovered wastes on soil quality.

What are the impacts of chemicals and other factors on rural soils? There is limited guidance on levels of contaminants in soil that pose a risk to soil quality, human health and the wider environment. Despite work to establish methods for assessing the risks from soil contamination, there is substantial uncertainty around fate, transport and impacts. There is a need to establish consensus on the principles of protecting soil quality, the methods of assessing risk and new or revised guidelines on protecting rural soils.

What is the effectiveness of nutrient control measures applied in combination? Agricultural measures to tackle nutrient losses are commonly implemented in combination. We need to understand how these bundles of measures affect soil nutrient content and losses to water for different soil types. We also need to update approaches for assessing nutrient losses to water such as the soil nitrogen balance, NEAP-N, and N-CYCLE. This will support water protection and engagement with farmers to achieve the requirements of the Water Framework Directive and Nitrate Directive.

How can phosphorus be managed more sustainably? Phosphorus is effectively a non-renewable resource and there is concern that its sources are rapidly diminishing. We need to understand the implications for the environment and the potential for reducing phosphorus inputs to water by using new technologies to recover phosphorus from wastewater.

How should we manage diffuse urban soil pollution? We need more cost-effective methods for assessing and managing soil and water contamination in urban areas. Historically, management of land contamination has focused on point sources, but more diffuse pollution may also be of concern to public health. The impact of widespread levels of contaminants such as asbestos, benzo[a]pyrene and lead in the UK is poorly understood. Research is needed on sources and exposures to diffuse pollution in soils, impacts on health and methods for regulation and risk management of both historical and novel contaminants.

Agriculture and land use

What are the likely impacts of rising water tables on pollution from urban soils? Urban soils and made ground are an important source of groundwater pollution. Many models consider the effect of water infiltration on the transfer of contaminants but few consider the effect of a sustained high water table on the fate and transport of contaminants. If water tables remain high in parts of the country from changing patterns of rainfall and reduced use, new methods are required to assess the risks to water quality.

What are the impacts of flood risk management on rural soils? Extensive coastal and river flooding results in waterlogging of soil which changes its properties and its ability to retard the movement of contaminants. Flood waters can be contaminated from upstream sources, leading to soil contamination as the water recedes. An increase in the dredging of river catchments will also result in a greater demand for the recovery of these potentially contaminated sediments to land. The impacts of contaminated sediments and flooding on soils need to be reviewed to inform sustainable flood risk management.

What are the effects of agriculture on air quality and how can we mitigate them? Agriculture emits a range of air pollutants that affect the health of ecosystems and people. For example, it emits bioaerosols, particulates, ammonia and odour from intensive livestock facilities that we regulate. Crops and trees emit precursors of photochemical pollution . We need improved understanding of the interactions between agriculture and air quality, and approaches that can allow sustainable growth in agriculture.

How can we predict changes in agriculture and its impacts on the environment? How will climate change, consumer demand and other changes affect crop types and agricultural practices in England? How will this affect water use, nutrient and silt run-off, and emissions of greenhouse gases and ozone precursors? How will pesticide and other inputs change, both from direct usage and waste management, including the application of compost, sewage sludge, and anaerobic digestate to land? What are the risks from potential aquaculture development in warm coastal waters in England? We need to understand the key trends to ensure our interventions and monitoring address the greatest risks.

Energy

What scientific tools and evidence do we need to support the UK's nuclear renaissance? The nuclear renaissance covers the building of new nuclear power stations, the decommissioning of old ones, interim waste storage and the development of a geological disposal facility for nuclear waste. There are 8 areas where new or updated data and tools are needed for regulation: (a) Facility management and decommissioning (b) Higher activity waste (c) Lower activity waste (d) Integrated waste management (e) Fuels and materials (f) Geological disposal (g) Land quality management (h) Radiation protection and environmental assessment (including proposed new reactor types).

How can we best manage the environmental risks of energy production? There are a wide range of current and potential energy generation options, many driven by the need to reduce greenhouse gas emissions. Existing and new power generation presents challenges for regulation and environmental management. We need to understand and mitigate potential adverse impacts while helping to ensure secure supplies. Existing thermal power stations, for example, may be constrained by future water availability. Some technologies may have limited impacts from each site but could combine to have larger effects: for example, how many water source heat systems can be operated on a river without changing thermal habitats and what are the ecological impacts? Developing technologies of interest include hydropower, water source heat pumps, bioenergy crops, tidal lagoons and fracking.

What are the risks of exploiting shale gas and how can they be managed? There is renewed interest in onshore fossil energy sources – shale gas, coal bed methane and even underground gasification can be added to the more traditional onshore oil and gas. Across these activities we need to:

• understand "baseline" environmental conditions and how to assess changes;

• understand the environmental risks from single and multiple sites, including to air quality, hydrogeology and geomechanics;

• develop risk-based interventions, guidance, monitoring and regulatory tools, from exploration through to decommissioning.

The issues relevant to our remit include emissions to air and their environmental and health effects; aqueous discharges and impacts on ground or surface waters; management of waste materials; the risks of seismicity on site operations and risks from well bore damage for example. While basic research is needed in some cases, analysis of existing information may answer many of the technical questions.

How well do mitigation measures protect biota from low-head hydropower in rivers? There are an increasing number of small scale hydropower installations in rivers. Some research is underway to evaluate the impacts and the effectiveness of mitigation measures, but more work is needed on fish passage around hydropower schemes and other abstraction intakes and structures.

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Energy

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What are the impacts of marine renewable projects on migratory fish? Wind turbines and other such developments may affect fish, particularly migratory species such as Atlantic salmon, sea trout, European eel and lamprey. The evidence gaps include the effects of underwater sound, physical injury from tidal/wave turbines and the risks from electro-magnetic fields.

Two 40-tonne Hydropower turbines installed at the Environment Agency's Romney Weir on the River Thames.

Industry and Better Regulation

Can we improve our persistence and bioaccumulation assessments of chemicals? The PBT (persistent, bioaccumulative, toxic) assessment is a driving force under the EU regulation on the Registration, Evaluation, Authorisation and restriction of CHemicals (REACH). The P assessment usually relies on the outcome of an environmental simulation test, while the B assessment is usually based simplistically on the bioconcentration factor. These measures have been criticised for being of low environmental relevance. We need to find better descriptors of persistence and bioaccumulation of chemicals in the environment. We need cheaper, quicker and less 'vertebrate animal intensive' methods covering a variety of taxonomic groups taking into account adverse outcome pathways, omics technologies, links from biomarkers to population end points, etc.

Are there better ways of prioritising PBT chemicals and chemical mixtures for risk management? Currently, all chemicals that meet the REACH PBT criteria are considered to pose an equal threat to the environment, without any safe threshold. We need better discriminatory descriptors to ensure that risk management is proportionate to the hazard. Chemicals also occur in mixtures and act in an additive and occasionally a synergistic manner, but regulation continues to take a 'one by one' approach to risk assessment. Can we identify situations where combinations of chemicals are of concern and develop a tool to assess this type of risk?

Can we improve our chemical exposure modelling? An overhaul of existing exposure models used in REACH risk assessments is needed to make them more representative and suited to sensitivity analysis (e.g. more advanced food chain models, variable dilution, climate change scenarios) and to provide clearer links to risk management options (including modelling of decay curves following emissions reductions). Socio-economic considerations about the benefits of controlling chemicals are also important – how far should we go in driving down emissions?

What are the risks of nanomaterials? A lot of research is underway on nanotechnology at an EU and global scale, much of this supporting developing regulation. However there are some issues of more immediate interest to the UK, including exposure and potential effects of nano-metals (e.g. silver, zinc) accumulating in river sediments to potentially harmful levels. The UK currently has a moratorium on the intentional release of unbound nanoparticles, which could be holding back development of new technologies, such as nanoremediation, which may offer environmental and societal benefits. Research into the fate, behaviour and effects of intentionally released nanoparticles is needed to help review the moratorium.

Industry and Better Regulation

How can we improve our assessment of diffuse and fugitive air pollution? Diffuse and fugitive emissions of air pollutants from industry, transport and waste sites can have ground level impacts, often near residential and conservation areas. The emissions are difficult to assess due to their uncertain and spatially distributed nature, and their impacts on sensitive habitats are often uncertain. We need smarter assessment methods for quantifying and managing diffuse and fugitive air pollution and its impacts to enable economic development without compromising local health and amenity.

How can we take account of air-quality/climate interactions when regulating major industries? Emissions from regulated industries such as power stations, refineries and onshore oil and gas sites affect local and regional climates by contributing to atmospheric aerosols. Conversely, the impacts of industrial emissions on local and regional air quality are altered by climate parameters like temperature, precipitation and atmospheric stability. We need to take account of these interactions, such as the contribution to regional dimming and the impact of an expanded onshore oil and gas sector on air quality under climate change.

How can we integrate data and modelling for managing air-quality incidents? During major air pollution incidents such as large fires or chemical releases, we have to coordinate monitoring and modelling data to support decision-making. We need tools which can integrate data from different sources and model outputs in real-time to give a clear view of the current and projected situation on the ground. The same tools could also be used to identify areas of measurement uncertainty and hence improve monitoring for routine air quality assessments around regulated sites.

How can we use meteorology to reduce air-quality impacts from regulated industries? Some meteorological conditions can increase impacts from industrial emissions on local communities, whereas other conditions ameliorate the effects. Can we use meteorological predictions to schedule emissions in order to minimise the risks? We need to develop systematic procedures for meteorological dispatch covering a range of emitter and receptor types so that these procedures can be adopted routinely.

How will the types of industrial processes in England change over the coming decades? What are the future trends in industry sectors and their implications for the environment and regulatory needs? What research or steps could we take now to facilitate our role and help enable economic development?

Waste

How do we manage the risks from using waste as a resource? Waste is increasingly seen as a resource to be recovered or reused. New waste treatment technologies, the innovative reuse of materials and new products provide regulatory challenges in managing and monitoring the environmental risks. New waste materials such as nanoparticles and microplastics may introduce new risks. Many treatment residues are destined for application to land and the environmental risks and benefits from this need to be understood. What do we need to know to assess these activities and the long term effects?

How should landfills be managed in the future? The diversion of waste from landfill may change the composition of landfills and hence the risks they pose. What are the changes and how can management techniques respond to deal with leachates and landfill gas? We also need better ways to measure and control methane emissions from landfills, and to assess the possible landfilling of low level radioactive waste.

What are the risks and how do we handle the wastes from dealing with animal, plant and human diseases? From time to time, epidemics of new diseases or reoccurrence of old diseases create environmental risks, for example from the handling and treatment of the wastes generated. What new and old diseases should we expect and what plans do we need to deal with them?

How can we better understand and tackle waste crime? There is a lot of uncertainty about the nature and scale of waste crime, and the impact it has on the environment and wider society. We need to better understand the range of legal and illegal waste sites, particularly around the misdescription of waste.

Tackling Waste Crime, Road Checks - Operation Cyclone

Water supply and the water environment

How can we improve water security? Water scarcity – temporary or permanent – is a real threat in England as a result of drought and demand for water. Evaluating the security and resilience of water supply is ever more important, particularly in the face of climate change. It is important to understand how water demand may change, when and where this presents risks and how it can be managed. This needs to take into account the wider social and economic aspects including global markets, particularly in food.

How much water do aquatic ecosystems need? Despite a growing body of research into this issue we cannot answer the fundamental questions of how much water can be taken out of rivers and lakes, how often, when and for how long, without causing unacceptable changes to ecology. What research do we need to address this and do we need to take a different approach?

How can we understand and manage hydromorphology and ecology more effectively? Physical catchment-scale alterations and river management affect hydromorphological processes and forms, including the movement of sediments. This has implications for ecological communities and the ecosystem services they provide. Better understanding of these interactions and the cost-effectiveness of river restoration is needed.

What is the importance of nitrogen in fresh waters to ecological function and recovery? Much attention has been given to the role of phosphorus in the eutrophication of fresh waters, whereas the focus for nitrogen has mainly been drinking water protection. As phosphorus concentrations are reduced by effluent controls we need a clearer understanding of the role of nitrogen in the ecology of rivers and lakes to inform management actions.

How are chemical thresholds linked to ecological status? Chemical thresholds such as environmental quality standards have adopted approaches taken from risk assessment, similar to those used under the REACH regulation. But these thresholds are not linked to the ecological status which lies at the heart of the Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD). As a result, chemical status and biological status are not aligned, and we have little understanding of the chemical concentrations required to achieve 'moderate' status if 'good' status is unaffordable. We need to understand how we can expect the biology to respond to changes in chemical contamination in order to evaluate the benefits and costs of improving chemical status.

Water supply and the water environment

Is there an ecological benefit in reducing nutrients from "very high" to "high" concentrations? Our ecological assessment tools show little response to changing phosphorus concentrations above certain threshold values. In lowland England in particular, this means that ecological improvement may not be apparent in response to investment in nutrient removal. We need to understand if other aspects of aquatic ecology, not captured by our methods, show responses to phosphorus that should be taken into account.

How can we give better protection to drinking water supplies? There are a range of problems we need to understand to protect drinking water sources from chemical contamination. These include the extent and nature of contamination of private supplies by local effluent discharges; the sources of chromium in drinking water, its speciation, and analytical methods for chromium; contamination of groundwater by metaldehyde from landfills.

What is the role of denitrification in groundwater nitrate concentrations? Nitrate is a widespread pollutant of groundwater and water supplies. Denitrification is the microbially mediated reduction of nitrate which decreases nitrate concentrations where it occurs. We would like to know the extent of denitrification in a range of aquifers and how it will affect the long term concentrations of 'legacy nitrate' in groundwaters.

What are the factors affecting microbial contamination of groundwaters? With the implementation of the Environmental Permitting Regulations (EPR) in 2010 we lost our ability to control pollution of groundwater caused by microbial contamination. This is causing us operational and regulatory problems. We need to identify, quantify and understand case studies of microbial contamination of groundwater drinking supplies.

Deep microbiology: how does our surface ecology relate to subsurface and deep subsurface ecology? As we seek to exploit new energy reserves in deep shales and other oil and gas formations onshore we will introduce microbial life to new horizons (assuming there are no indigenous organisms or resting forms). At shallower depths, the microbial population of aquifers combined with the unsaturated zone is an essential protection for existing groundwater resources. We need a much improved understanding of the microbial ecology of the subsurface, its functions and how it may be affected by human activities.

How do we need to manage Invasive Non-Native Species? We need to assess the impacts of invasive non-native species on ecology and on ecological status as measured for the Water Framework Directive. We also need to assess the effects on flood and coastal risk management. We need more effective detection and monitoring methods, practicable containment (biosecurity) measures and cost-effective control methods. We need to understand how these species spread, and how they may respond to factors such as climate change.

Water supply and the water environment

How can we use spatial/temporal models and data to improve monitoring networks? With pressure on monitoring costs, we need to think about how modelling can inform monitoring and vice versa. What is the potential for questions about the state of the water environment to be inferred from modelling based on existing datasets, and how could this guide the design of monitoring networks?

How do time lags, species population dynamics and long term trends affect environmental assessment? We assess changes in water quality and ecological status on relatively short timescales, typically over a few years. Yet many environmental problems, such as nitrate in groundwater, develop through long term pressures and respond very slowly to interventions. Species populations patterns over the long term are also affected by natural variation and responses to climatic changes, influencing the results of monitoring and impact assessment. We need to improve our understanding of such long term changes to ensure that management achieves sustainable outcomes.

Environmental Monitoring Officer with a virile and signal crayfish

Understanding Flood Risk

What blue skies thinking or radical alternatives could deliver more effective Flood and Coastal Erosion Risk Management (FCERM)? Legislation and major flooding events have driven the way that flood risk management is funded and managed across England and Wales. But is also acknowledged that the government has insufficient resources to maintain all current flood defences and build new defences in high risk areas. There have also been changes in agreements with the insurance industry and the right of local residents and businesses to contribute to flood risk interventions. With population increases, pressure to develop in areas at flood risk and the risks of climate change, can the current system survive a growth in demand or are there radical alternatives to flood risk governance and funding?

Can we be smarter about exploring future uncertainties? We use modelling to support our long-term investment strategy and appraisal of flood risk management schemes. At the 100 year timescale the influence of future uncertainties, for example those attributed to the economy and climate change, become substantial. With a fuller understanding of future uncertainties we could create flood risk management strategies that are more resilient and able to adapt if needed. Resources limit the number of model runs used to explore future scenarios, but are there smarter ways to use modelling to understand future uncertainties?

Can we make long-term flood risk management planning more interactive? Making long-term strategic flood risk management decisions is challenging, and engaging with others to do this in a consensus driven way can be particularly so. A more interactive approach to national scale, long-term modelling to allow users to explore the impacts of changes could support this. It could be made available online. Is it possible to produce computer models that are credible but flexible enough to allow for an interactive user experience for communities and others?

Can we resolve the challenges of institutional geography and physical geography? Institutional boundaries vary from national scales (Defra), to multiple counties (Environment Agency Areas) to county or city scales (local authorities). Strategies for flood risk management operate at catchment scales or along stretches of coastline. Authorities and land owners who manage land, riparian zones or channels can operate from catchment to field scales, while their actions may affect flood risk locally or further afield. Given these complex institutional and environmental geographies, do we understand the economic or efficiency impacts of our current flood risk management approaches? Where are the impacts felt the strongest? And what innovations can reduce the effects of this inherited system within which flood risk management operates?

Understanding Flood Risk

How can we design more complex flood models while understanding their uncertainty and precision? Over the last 10-15 years, flood risk modelling has seen a shift from coarse 1-dimensional models to detailed 2-dimensional models; and more recently, 3-dimensional models are being considered. Combine this with developments in probabilistic and multi-scale modelling, as well as the desire for larger, higher resolution model domains with shorter run-times and more accurate outputs and we find ourselves adding further uncertainty. For example, sub-metre LiDAR enables 2-D flood-plain modelling with precise position depths and hazard across the floodplain, but models still make crude assumptions about surface water drainage rates and how buildings store or deflect flows. We need to know the knock-on effects of improving model components and the impacts of adding assumptions when we increase the data requirements 100-fold but only supply 10 times more data.

Is all-in-one modelling a feasible and useful goal? Will we ever generate flood risk models that incorporate the entire environment? Computers are becoming more powerful, environmental sensors are invading our world, the internet knows where we are most of the time, data exists covering most aspects of our environment. We can observe, replicate and forecast many aspects of our environment: weather, habitats, sediments, structural deterioration, landscapes, population behaviour, etc. Can we ever combine all this information to predict risk? What is the value of combining all these disparate models into one?

How can we improve groundwater flood models? The winter 2013/2014 groundwater flooding has provided new data that can be used to develop groundwater flood models. We have regional groundwater resources models for principal aquifers in England. We need to assess whether these can be adapted and calibrated to simulate groundwater flooding or if new models are needed. There are two main scientific challenges: first, to understand where groundwater accumulates on the surface; secondly, to model the impacts of human activities in the subsurface and how they affect groundwater flood patterns.

Are there better ways to value the multiple benefits of flood risk management? Economic appraisals of the benefits of flood risk management consider a limited set of benefits, focusing on damages avoided to infrastructure. We know there can be other societal and environmental benefits, yet these are rarely considered in the same way. For example, flood risk management measures that include green infrastructure or improve deprived areas. To ensure the right management measures are selected we need a more comprehensive approach for assessing the whole life benefits. New evidence and data are needed, as well as tools to include multiple benefits within economic appraisals.

Managing Flood Probability

How can we work with natural processes and use catchment laboratories? We know that natural approaches to flood management work in small catchments; we also know that these measures can benefit sediment management. But uptake of these types of measures has been slow. Although we have modelled evidence of their effectiveness, we are at an early stage of collecting evidence to establish their flood risk benefits. There are aspects which need further testing in the field as well as funding and perception barriers which reduce the level of uptake. To bridge some of these gaps we want to work with partners to set up 'catchment laboratories' to implement and test natural approaches to flood management. This will build on the work of the DEFRA demonstration test catchments. The laboratories would cover a range of spatial scales and catchment types (urban, rural, coastal and estuarine). In rural locations we would want to test different land management measures, the effects of woody debris and grip blocking, and look at ways of modelling sediment processes. In urban locations we would want to explore what natural approaches to flood management look like and how effective they can be.

How resilient can we get - how resilient do we need to be? The concept of resilience in flood and coastal erosion risk management covers work to prepare for, resist, recover from and adapt to, flooding and erosion events. The key drivers of risk – climate and socioeconomic change – demand that we become increasingly resilient in the future, but how? The gaps in our knowledge are considerable, for example, can we clearly express how resilient we are now? How do we best invest for the future to improve resilience across flood and erosion systems? How do we ensure that decisions we take today don't leave future generations with expensive legacy infrastructure which has closed off possible adaption strategies? How can we design today's infrastructure to transition to future change?

How should we prioritise our investment for the future? Prioritisation of resources to build, maintain, operate and decommission flood and erosion risk management assets is a major challenge. We need to refine our answers to the following questions: i) How do our flood and coastal risk management assets (both built and natural) perform during extreme events and deteriorate over time, both now and when allowing for future climate and social change? ii) How can we work more with natural processes to balance the objectives of flood risk management with the needs of the environment? iii) How can we quantify the full range of benefits and costs (economic, societal and environmental) over the whole life of the assets we manage?

Managing Flood Probability

How can we better adapt to long-term climate-related change on the coast? Climate change will lead to increases in sea levels. Together with storm surge and other climate impacts our coastline will evolve over the long term, increasing the risk of coastal flooding and erosion in many locations. In some places it will be no longer sustainable to build new coastal protection structures or maintain existing ones, we will have to adapt. What adaption strategies can be used (innovative and conventional)? How effective are they and can we develop improved methods to test the suitability of different adaption strategies/scenarios for a particular location? How can we better use natural systems, e.g. intertidal habitats, to help mitigate flood and coastal erosion risk? How can we work better with local communities to understand their needs and help them to adapt? Scientists within the iCOASST project are helping to improve our prediction of long-term, large scale geomorphic change on the coast and we need to build on learning from the Coastal Change Pathfinders projects and elsewhere.

How can we better manage mixed beaches? The Environment Agency and Local Authorities spend over £20 million annually on beach nourishment and management. There are predictive tools for beaches that are either predominantly shingle or predominantly sand, but most beaches are mixed sand and shingle and there are no tools for these. How can we predict the behaviour and response of mixed sand and shingle beaches?

How will ageing reservoirs stand up to combinations of extreme weather? Climate change predictions forecast that we will experience greater extremes of weather conditions in the UK through the coming years. The service life of a reservoir is many years and through that period it may experience new extremes of rainfall, drought, heat and cold that were not anticipated when it was built. How will the combinations of extremes impact the potential failure modes of the UK's ageing stock of reservoirs in the long term?

What are the safety risks of small reservoirs? The Flood and Water Management Act 2010 made provision for a risk-based approach to managing reservoir safety, including "high risk" reservoirs above a capacity of 10,000m^3, below the previous 25,000m^3 threshold. Little is known about the risks presented by these smaller reservoirs or about the impacts of introducing regulation.

How can we use innovative technologies to provide a richer insight into asset performance? Routine visual inspection and engineering investigation are crucial to our asset management. But these surveys only provide us with a snap-shot of asset condition, with limited geographical coverage and involving many assumptions around how condition relates to performance. Remote sensing and non-intrusive geotechnics combined with new technologies for continuous monitoring could offer powerful ways to improve decision making and operational response. The challenge here is to develop proportionate, risk-based approaches that deliver practical solutions at reasonable cost.

Managing Flood Probability

Is there a role for communities, business and charities in operating and maintaining FCERM assets? Delivering new infrastructure collaboratively with local communities has many benefits: i) communities at risk directly influence decisions that affect them; ii) awareness of the risks improves; iii) funding can stretch further with more benefits. On the downside, collaboration around the maintenance and operation of these new assets is harder: i) people feel that they're being asked to look after something that they've already paid for; ii) a long-term, continuous commitment is needed; iii) the required capacity and training can be extensive. Research to help develop new models of collaborative delivery is needed to answer questions such as: Would a longer-term programme which combines investment in both new and existing infrastructure result in greater collaboration? What opportunities can mobile technologies offer? What are the barriers to collaborative maintenance and how can these be overcome? What is the role of communities when decisions are taken to stop maintaining? What is fair and equitable?

Do we understand societal perception and engagement on new approaches to flood risk management? Increasingly we are using new approaches to manage flood risk such as Sustainable Drainage Systems (SuDS), temporary defences, working with natural processes and no longer maintaining some defences. Some of the biggest barriers to using these new approaches are societal. For example, a community might oppose dual use of a recreational area for flood storage. Why do some communities oppose these new approaches while others champion them? Do communities believe that novel approaches will protect them as well as traditional approaches? Do perceptions change over time? What are the best ways to convince communities of the benefits of new approaches?

Cockermouth 2009

Managing the Consequence of Flooding

In the end it is all water, wind or mud – can we integrate forecasts of the impacts of flooding from any source and wider natural hazards? When you are affected by natural hazards, be it flooding, storm damage, or landslides, the exact source is probably of less concern than the impact and what you can do about it. With recent advances in modelling and computing, the time is ripe to further integrate our approaches to forecasting flooding from any source and risks from other natural hazards to focus on what really matters to people and responders. There is much scope to push the boundaries by linking and integrating different models for forecasting and visualising overall flood risk (rivers, coasts, waves, surface and groundwater) and its impacts in real time.

Crowdcasting – how can everyone help to forecast flooding? Flooding can affect anyone – where you live, where you work or where you just happen to be at the time. The good news is that all of us can help to detect, warn and ultimately take action to minimise its impacts by sharing experiences. The question is how could communities and practitioners work together to develop and run a truly collaborative monitoring, forecasting and warning service community building on people's personal experience? How could we benefit from wider observations and experiences people have beyond our traditional monitoring and forecasting networks to get a better picture of what is flooding right now and what might in future?

Can we develop new tools to support decision-makers in the face of uncertain forecasts? Probabilistic flood forecasts already exist, but practitioners find it difficult to turn them into actions on the ground because confidence tends to be too low. Are there new approaches risk management authorities could use when deciding how to respond to probabilistic forecasts that balance the risks of not responding against the costs of operational action? Or could new operational responses be developed that are effective yet low cost so that they can be undertaken even with low confidence forecasts?

Flooded street, Witton 2007

Environment Agency

Climate change impacts and adaptation

How can we better understand climate change impacts in the UK? Much research addresses global and regional changes in climate, but the impact of these changes remains poorly understood. We know that climate change affects the global hydrological cycle. A warmer atmosphere holds more moisture, with potential for more heavy rainfall and floods. UK-scale impacts are harder to understand, although most projections suggest more frequent and larger winter floods, and drier summers. We also expect the UK climate to be warmer, altering the rates of biological and chemical processes in soil and water with direct effects on species distribution and behaviour as well as indirect effects, for example through changes in water quality. However, we are very unclear about how big such changes might be or when they may occur.

Specific research questions include:

- Which species associated with the water environment are most vulnerable to climate change?
- How much change should we expect in water temperature, nutrient concentrations, dissolved oxygen and the populations of aquatic plants and animals?
- How much surface water is really available in catchments?
- How resilient is groundwater to climate impacts? How much resource remains unquantified? What is the potential in the UK for using aquifer storage and recovery, and abstraction from secondary or deep aquifers?
- How might the availability of water for agriculture change?
- How does land-use change affect water availability and environmental quality?
- Are there climate change thresholds that will lead to non-linear responses in UK catchments?

How will changes in hydrohazards affect us? Sea-level rise will change the incidence of coastal flooding as well as erosion and sedimentation patterns. Hydrohazards – floods, droughts, poor water quality and soil erosion – remain poorly understood, yet this is how many people will experience the impact of climate change. Water quality and soil erosion are less well researched than floods and droughts. More work is needed on the future incidence of all of these hazards, their impact on people and livelihoods, and possible measures to reduce their impact.

Specific research questions include:

- How should we plan for uncertainty in future sea level rise?
- How will sea level rise and changing river flow affect estuarine flooding?
- How does groundwater respond to extended droughts? Can we identify and understand non-linearities in groundwater response? Does groundwater recharge change?
- What happens to the environment during and after extended or severe droughts?

Climate change impacts and adaptation

Adaptation: what measures are needed and how can we make them happen? Despite an increasing understanding of climate change, action on adaptation remains patchy. Flood protection and water supply planning both consider climate change, although even here we could do more to consider the plausible extremes. In other areas there is much less adaptation. Which adaptation measures are most effective? What are the social, institutional and technical barriers to adaptation? How can we encourage effective adaptation, how can we measure it and how much does it cost? What kinds of data, information and tools really help people take account of climate change in decision making?

- What does a resilient public water supply system look like?
- How can hydrological forecasting be improved for real-time based forecasting to support future water abstraction systems?
- How can catchment management benefit water resources?
- How will changes in reliability of water resources be managed at the farm/catchment scale?
- How effective will interventions such as catchment sensitive farming and restoring sustainable abstraction be under climate change?
- How do we best promote catchment management actions that include planning for climate change?
- Which catchment schemes give the greatest benefit? Where might catchment schemes aimed at other objectives (water quality, flood relief) give co-benefits for water availability?
- What measures can be taken to help habitats and species become more resilient and adapt to climate change?

Ullswater

Technology and innovation

Cost-effective monitoring of the environment. Measuring pressures and impacts in the environment is a key duty for the Environment Agency but we are under pressure to rationalise monitoring and reduce costs. The challenge is to identify novel ways of maintaining capability or to provide new insights into changes in the environment as cost-effectively as possible. Five examples are highlighted below.

I. **Improved monitoring through molecular biology.** Recent advances in molecular biology (such as DNA bar-coding) together with increased throughput and reduced costs are opening up opportunities for more accurate and cheaper monitoring. We are beginning to demonstrate the practicality of these methods, but how might they be applied across the spectrum of monitoring and assessment activities? How can these techniques enhance our capabilities in environmental diagnostics?

II. **Passive sampling technologies.** Spot sampling of air and water is the way we have monitored their chemical quality for decades, yet such samples represent only a tiny proportion of a year and yield uncertain results. Passive samplers can detect and quantify dissolved concentrations of a wide range of chemicals over extended periods and we already have experience of using them in air and water. These techniques need to be explored further where (a) we need to sample mobile media (b) time integration is needed and (c) the alternatives are costly or problematical (e.g. biota sampling).

III. **Unmanned aerial vehicles (UAVs).** UAVs are starting to be used to survey waste sites, monitor aerial emissions and inspect assets. How can we deploy them cost-effectively and safely, and with a high level of public acceptability?

IV. **Earth observation.** Satellite techniques offer opportunities to assess flooding, land use, habitats, water quality (e.g. chlorophyll in surface waters) and other variables or proxy indicators over wide geographical areas, including small or remote sites that are currently not monitored due to cost. We would like to ensure that work in this field takes into account the needs of environmental managers, including consideration of costs and handling the very large amounts of data generated.

V. **Sensorwebs.** We lve in a time where your smart phone can link to your heating and your fridge might talk to your supermarket. Technologies developed for the Internet of Things offer the potential to make more timely and direct measurements in the field with sensors rather than in a laboratory; assets such as flood gates, and other ‘things’ could automatically connect, talk to each other and take pre-emptive decisions during flood incidents. This could make management more responsive, interactive and more efficient.

Technology and innovation

Collecting data from beneath your feet. Many drainage systems were built in Victorian times and the original records of their design and construction have long since been lost. With assets above the surface it is relatively easy to collect such data and to carry out inspections. Getting underground is much more difficult. Some approaches exist, such as ground penetrating radar or robots with video cameras which are used in specialist applications. Could a more widespread and cost effective approach be developed?

Real time control of drainage systems. Most of our drainage systems are designed passively, in that water flows into them and then flows downhill. But perhaps we could get more from them if we could close off certain parts of the system when they become full and redirect the water elsewhere. Could cities be designed to manage flows on the surface, perhaps by automatically dropping a road kerb to allow water to spill in to a nearby park? To make this work we need drainage systems that can be remotely controlled, and real time data to feed the system. To be cost effective it needs to be something we can retrofit to existing systems.

Big Data. Remote sensing and new sensor technologies are generating very large environmental data sets that need new software to manage, analyse and visualise. What other sources of Big Data and systems will provide the services and modelling capabilities that we need and how can they advance our shared understanding and management of the state of the environment?

Using new materials to improve our assets. Steel and concrete have been in widespread use in construction for over a hundred years and plastics since the middle of the last century. Recent developments in nano materials have produced coatings that could make assets waterproof or mould resistant; scientists have made self-healing plastics and self-healing concretes. What are the new materials that will help us build assets that are cheaper, perform better and require less maintenance?

Waterproofing our pipes and sewers. When groundwater levels are high, water infiltrates underground pipes and sewers, reducing their capacity to drain surface water and prevent flooding. If the pipe is a combined sewer this can also cause sewage to overflow. Is it possible to reduce groundwater infiltration without the huge expense of digging up and replacing pipes?

Cross-cutting research

How can we improve our economic evidence to support decision-making? We use monetary values to estimate the environmental and social impacts of changes in the environment as part of our appraisal of interventions. This is important to help avoid the risk of making poor decisions on investment in our natural assets. Recent changes in the policy and regulatory landscape mean we need to update our evidence base to meet the future needs of water and flood risk planning. We will be working with the Defra network and research bodies to scope and implement a work programme towards new valuation over the next few years.

How should we apply an ecosystem approach to managing the environment? A number of policy drivers promote an ecosystem approach but adopting this remains a technical and practical challenge. An ecosystem approach is a strategy for the integrated and sustainable management of land, water and living resources, allowing the value of the natural environment to be taken into account during decision making. Work is needed to understand the barriers that are hindering this approach and to develop solutions that will help to implement it, particularly at the landscape scale. This could include developing indicators of ecological status linked to the provision of ecosystem services.

What is the effectiveness of our interventions – how do we evaluate what works? Research about the effectiveness of Environment Agency interventions (such as environmental regulation, advice, guidance, engagement, environmental planning, flood warnings, flood defence schemes) is increasingly important, particularly in relation to small and medium-sized enterprises. It enables us to assess how effectively and efficiently we deliver our remit and to make the most of our resources. This research includes the environmental, economic and social impacts and benefits of our work, as well as learning and insights into the effectiveness of delivery processes. Links to other 'What Works' research in Government and the Economic and Social Research Council are of interest for any transferable learning to our work.

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Mud flats in winter. Sand Bay, Weston-super-Mare, February 2010.

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