Collaborative Research Priorities for the Environment Agency 2015 to 2019

Evidence Directorate | December 2014

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 of 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. Our expertise and extensive data sets are an important research capability and resource.

Our priorities are considered under 11 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.

Research themes

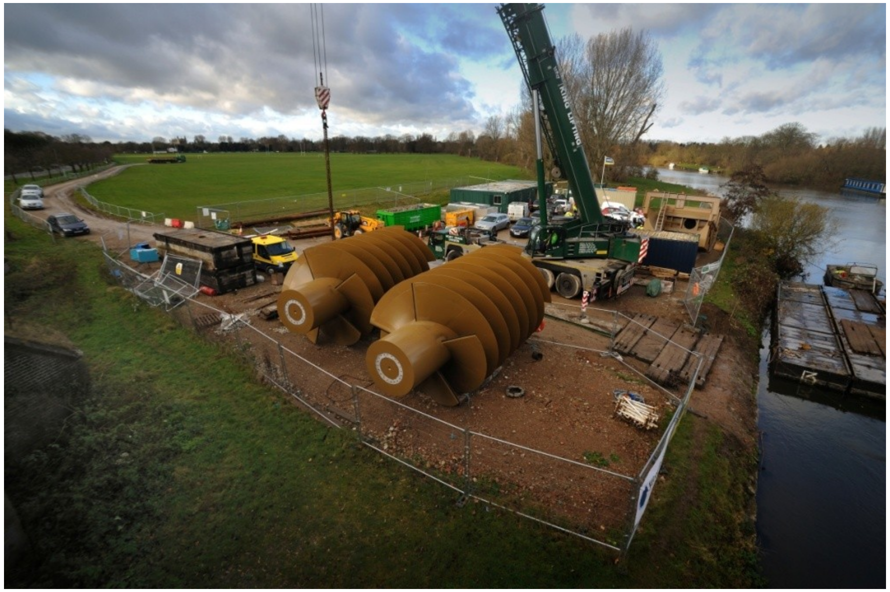
Agriculture and land use: rising food prices, food security, population growth and other pressures are driving changes in agricultural production and land use. We need to understand changing farming practices, how soil and water resources are affected and how we can best work with farmers and other land 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 new nuclear 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 for the spreading of wastes 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.



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

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Research themes

Understanding flood risk: is essential to flood and coastal erosion risk management. We need to predict and plan for environmental change and events that may not have happened before. This requires a good understanding of processes and reliable 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 their 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. Increasingly, research should also focus on using natural features such as river channels, dunes and beaches, taking 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 to develop awareness of flood risk and establish how this can be translated into responses to flood events by 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. This helps to target improvements and includes evaluating 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 an estimated 3,000 fish were killed following a pollution incident on the River Crane and the Duke of Northumberlands near Twickenham. **Incident room staff** monitor river levels over night 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 also uses 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 levels of contaminants in soil including novel contaminants such as nanoparticles (e.g. silver or cerium dioxide), perfluoro alkyl compounds, pharmaceuticals,veterinary medicines, pesticides and flame retardants. This is needed to provide baseline data to assess the impact of material applications such as recovered wastes on soil quality and the effectiveness of regulation.

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, the uncertainties around fate, transport and impact remain high. There is a need to establish a consensus on the principles of protecting soil quality, the methods of assessing risk and new or revised guidelines on protecting rural soils.

Predicting changes in agriculture and 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? We need to understand the key trends to ensure our interventions and monitoring address the greatest risks.

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 to assess 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.

Phosphorus recovery – delivering ecological improvement differently? 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.

Agriculture and land use

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.

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 limit the impacts of intensifying agriculture while not stifling production.

What are the risks to salmon and sea trout in England from potential aquaculture development? There are currently no sea trout, Atlantic salmon or Pacific salmon farms in English seas but demand could drive new developments. The Food and Agriculture Organisation predicts world seafood consumption will continue to rise while the EU has stated that we must prepare to meet this growing demand. How will the experience in Scotland translate to warmer waters in England?

Energy production

Scientific tools and evidence to support for 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).

Managing the environmental risks of energy production? There are a wide range of current and potential future energy generation options, many driven by the need to reduce greenhouse gas emissions. Existing and new power generation all presents challenges for regulation and environmental management. We need to understand and have options for mitigating potential adverse impacts while enabling secure supplies. Existing thermal power stations, for example, may be constrained by future water availability. Developing technologies in question include hydropower, water source heat pumps, bioenergy crops and fracking.

Shale gas. The potential exploitation of shale gas in England raises many questions. The long term effect of mechanical damage to extensive volumes of deep geological formations is unclear. How might deep groundwater be affected? How will we best monitor for impacts to geology, water supply and atmosphere?

Mitigating the impacts on biota of low-head hydropower in rivers. There has been a large increase in the number of small scale hydropower installations in rivers and there are applications in progress for many more. Some research is already underway to establish the potential effects on river ecology, especially fisheries, and to identify mitigation measures, but more is needed. Some of the results will be transferable to other technologies such as potable water abstraction intakes and flood risk management structures.

What are the impacts of marine renewable projects of migratory fishes? Wind turbines and other marine energy sources are playing an increasingly important role in meeting the UK's targets for renewable energy. Evidence gaps remain in our ability to assess the risk of such developments to fisheries, particularly migratory fish (such as Atlantic salmon, sea trout, European eel and lamprey). This includes the effects of underwater sound, physical injury from tidal/wave turbines and the risks from electro-magnetic fields.

What are the ecological impacts of utilising river water in heat exchange systems? There have been a number of proposals for utilisation of river/lake/TraC waters for both heating and cooling of domestic and commercial properties. Given that temperature is a fundamental driver of biological activity and a major determinant of ecosystem structure, these installations have the potential to impact on WFD ecological status and upon a range of ecosystem services. We need to understand their impacts on aquatic ecosystems.

Industry and Better Regulation

How will the types of industrial process that take place in England change over the coming decades? What are the environmental implications of future trends in industry sectors?

Chemicals: can we increase the sophistication of our persistence and bioaccumulation assessments? 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 to ensure that we can capture cost-effectively all chemicals that can persist for a long time in the environment and bioaccumulate in wildlife. In general, our tests for long-term toxicity in aquatic and terrestrial organisms are resource intensive and cover a very small number of species. 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.

Chemicals: 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 necessary to make them more representative and suited to sensitivity analysis (e.g. more advanced food chain models, variable dilution, climate change scenarios, etc.) and to provide clearer links to risk management options (including modelling of decay curves following cessation of emissions). Socio-economic considerations about the benefits of controlling chemicals are also important – how far should we go in driving down emissions?

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Industry and Better Regulation

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 further analysis of the exposure and potential effects of nano-metals (e.g. silver, zinc) found to be accumulating in river sediments at potentially harmful levels. Also the UK currently has a moratorium on the intentional release of unbound nanoparticles, but this could be holding back development of new technologies such as nanoremediation, which may offer environmental and societal benefits. Research to better understand the fate, behaviour and effects of intentionally released nanoparticles is needed to help review the moratorium.

Air quality: assessment of diffuse and fugitive air pollution from UK industries and transport. Diffuse and fugitive emissions of air pollutants from industry, transport and waste sites can have ground level impacts, often near residential and conservation areas, due to their broad spatial distribution and near ground sources. 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.

Air quality: 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/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 change parameters like temperature, precipitation and atmospheric stability. We need to take account of these interactions, in particular the contribution to regional dimming and the impact of an expanded onshore oil & gas sector on air quality with climate modification.

How can we integrate data and modelling for managing air-quality incidents? During major incidents impacting on air quality (such as large fires or chemical releases) we have a duty to coordinate the collection of 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 performance, 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 promote adverse 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.

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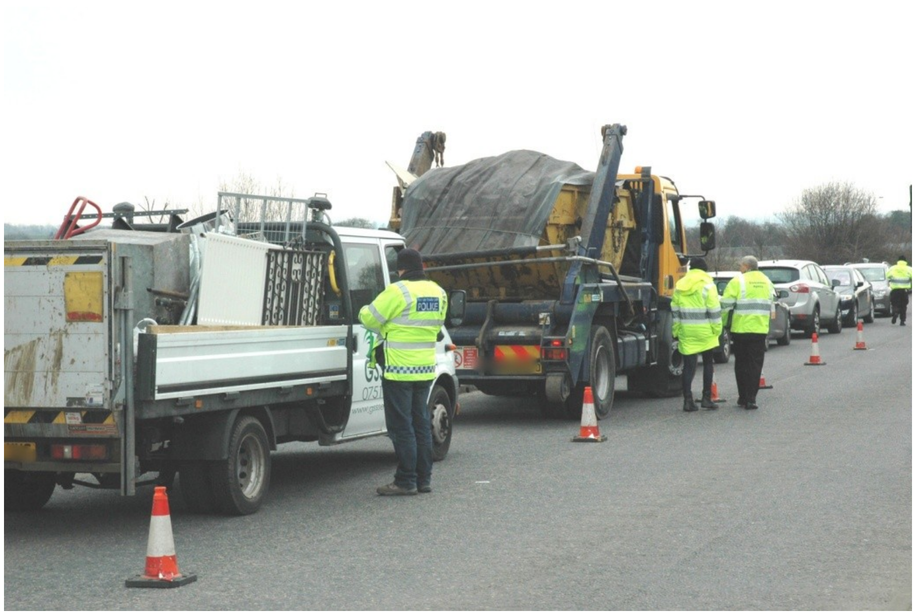
Waste

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 ensuring that the environmental risks are managed and monitored. New waste materials such as nanoparticles and microplastics may introduce new risks to the environment. Many treatment residues are destined for application to land and the environmental risks and benefits from this need to be understood and adequately managed. What do we need to know to assess these activities and the long term effects?

Changes to landfill. The diversion of waste from landfill may lead to a change in the composition of landfills and hence to the risks they pose. What are these changes and how do management techniques need to respond to deal with leachates and landfill gas? We also need better ways to measure and control the continuing problem of methane emissions from landfills, and to assess the possible disposal of low level radioactive waste to landfill.

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 waste materials generated. What new and old diseases should we expect and what plans do we need to deal with them?

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 continuum between legal and illegal waste sites, particularly around the misdescription of waste.



Tackling Waste Crime, Road Checks - Operation Cyclone

Water supply and the water environment

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.

Fish and flows. 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?

Understanding hydromorphology-ecology interactions. Physical catchment-scale alterations and the management of rivers affect the hydromorphological processes and forms of a river system, 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.

Nitrogen in freshwaters – what is its importance to ecological function/recovery? To date there has been much attention given to the role of phosphorus in eutrophication of freshwaters, 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 (alone and in combination with phosphorus) in the ecology of rivers and lakes to inform management actions.

Linking chemical thresholds to ecological status. To date, chemical thresholds like environmental quality standards have adopted approaches taken from risk assessment, similar to those used under the REACH regulation. However, the thresholds are not linked to ecological status which lies at the heart of legislation like the Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD). As a result, chemical status and biological status may not align, and we have little understanding of the chemical concentrations required to achieve ‘moderate’ status if ‘good’ status is unaffordable. River basin managers need to understand how we would expect the biology to respond to changes in chemical contamination when balancing costs against improvement in chemical status.

Is there an ecological response to reduction in nutrients from “very high” to “high concentrations”?
Our current ecological assessment tools tend to stop showing a response to increasing phosphorus concentration above certain threshold values. In lowland England in particular, this means that it is often not possible to report whether any ecological improvement has occurred as a result of reducing nutrient concentrations.

This may lead to a perception that investment in nutrient removal is not worthwhile in these situations. However, there may be other aspects of aquatic ecology, not currently captured by our tools, that do respond at high nutrient concentrations and would show benefits from the measures being taken.

What do we need to do to give better protection to private water supplies? We need to understand the extent and nature of contamination of private supplies from local effluent discharges (rather than diffuse or larger industry point sources).

Nitrate in groundwater. 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.

Microbial contamination of groundwaters – UK case studies. With the implementation of the Environmental Permitting Regulations (EPR) in 2010 we lost our ability under the Water Resources Act, 1991 (WRA) 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. The microbially mediated attenuation of contaminants is a key factor in mitigating the potential impacts of contaminants from both diffuse and point sources. We need a much improved understanding of the microbial ecology of the subsurface, its functions and how it may be affected by anthropogenic activities.

Chromium contamination. The genotoxic carcinogenicity of hexavalent chromium has been established and the UK Technical Advisory Group have identified it as a hazardous substance under the Groundwater Daughter Directive. The current UK Drinking Water Standard is 50 ug/L for total chromium but a guideline for hexavalent chromium could be much lower. We are interested in work on the possible sources of chromium in drinking water, its speciation, and analytical methods for measuring and speciating chromium in water samples.

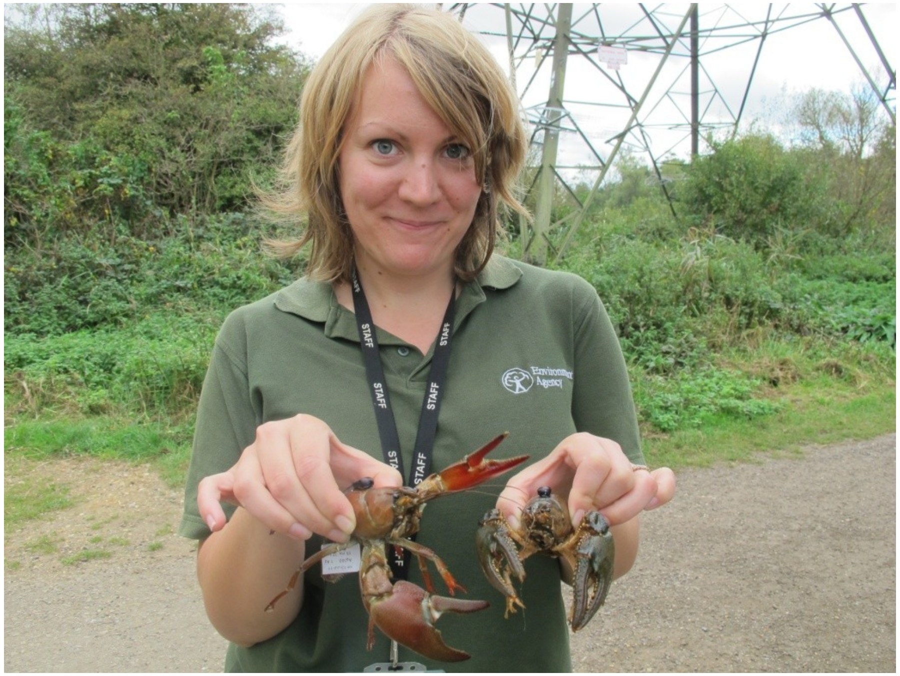
Water supply and the water environment

Metaldehyde in landfill leachate – UK case studies. Water companies have identified instances of contamination of groundwater drinking water supplies by metaldehyde thought to be generated in landfills. A study to quantify this problem is required to inform management of sites affected.

Use of spatial/temporal models and observed data to improve monitoring network design and decision making. With pressure on monitoring costs, we also 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 and trends in ecology and water quality to be inferred from modelling based on existing datasets, and how could this guide the design of future monitoring networks?

Invasive Non-Native Species. We need to quantify the impacts of invasive non-native species on ecology and on ecological status as measured for the WFD. We need to develop cost-effective methods for their control, including practicable biosecurity measures.

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 anthropogenic practices and respond very slowly to interventions. Species populations patterns over the long term are also affected by natural variation and responses to climatic cycles, influencing the results of monitoring and impact assessment. We need to improve our understanding and communication 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 FCRM? The Water Act 1995; the creation of the Environment Agency in 1996; the Easter floods of 1998; the Autumn floods of 2000; the Civil Contingencies Act 2007, the summer floods of 2007; the Floods and Water Management Act 2013: this list comprises some of the key drivers of the way that flood risk management is funded and managed across England and Wales. In parallel with the development of flood risk governance, has been the acknowledgment that the government has insufficient resources to maintain all current flood defences and build new defences in high risk areas. There have also been major 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 climate change meaning that the risk is set to grow, can the current system survive a growth in demand or are there radical alternatives to flood risk governance and funding?

Can we improve long-term flood risk management planning? We already undertake long-term modelling to support our long-term investment strategy for flood risk management. This comprises of economic appraisal out to a hundred year time frame, looking at expected cost and benefit (damages avoided) at a national scale under a range of investment scenarios. We currently do this modelling in a deterministic way, looking at a limited range of future scenarios. At these timescales the influence of future uncertainties including, for example, those attributed to the economy and possible climate change become significant. At the national scale, complexity and architecture of current models limit the number of model perturbations that we can practically evaluate. In the future could we adopt new approaches to this modelling or decision making techniques to better plan our long term strategy?

Can we make long-term flood risk management planning more interactive? Making long-term strategic flood risk management decisions can be challenging, and engaging with others to do this in a consensus driven way can be particularly challenging. A more interactive approach to the national scale long-term modelling to allow users to see the impacts of changes is important to support this. It could perhaps even be made available online in the future to aid discussions with communities and others. Is it possible to produce computer models that are sufficiently grounded in physical processes to retain credibility but flexible enough to allow for a truly interactive user experience?

Understanding Flood Risk

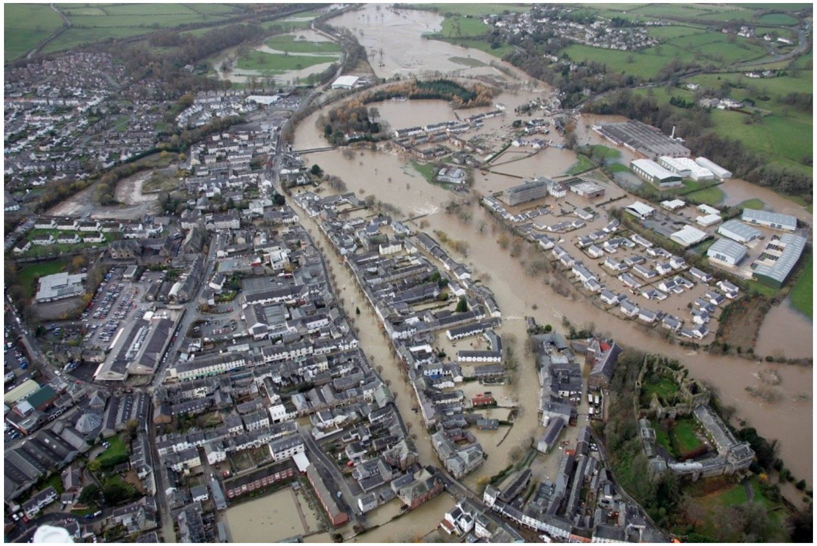
Can we resolve the challenges of institutional geography and physical geography? Institutional boundaries vary from national scales (Defra), to multiple counties (Environment Agency Areas) to county or city scales (local authorities). Strategies which outline approaches to flood risk management and reduction operate at catchment scales or along long reaches of coastline. Authorities and land owners who manage land, riparian zones or channels can operate from catchment to field scales, whilst the management option may affect flood risk locally or further afield. The physical properties of catchment and coast and their processes which define the characteristics of flood risk operate at multiple scales. In light of these complex institutional and environmental geographies, do we understand the economic or efficiency impacts of our current flood risk management context? Where are the impacts felt the strongest?

And what innovations can reduce the affects of the complex inherited system within which flood risk management operates?

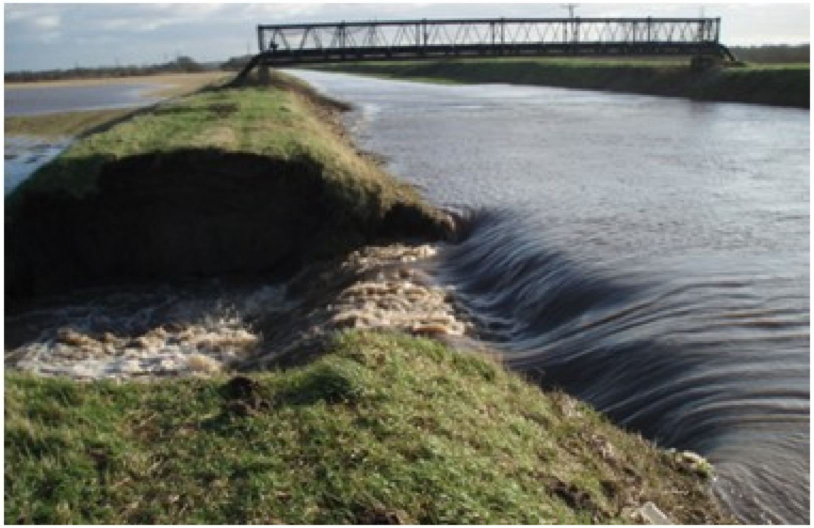
Flood model uncertainty and precision. Over the last 10-15 years, flood risk modelling has seen a shift from coarse 1 dimensional models to detailed 2 dimensional models; and more recently, 3 dimensional models are being considered for specialist flood risk applications. Combine this with developments 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 – we find ourselves adding further uncertainty – either perceived or actual. For example, sub-metre LiDAR enables 2d flood-plain modelling to precisely position depths and hazard across the floodplain but models still routinely make crude assumptions about surface water drainage rates and how buildings store/deflect flows. So, do we know the knock-on effect of improving any particular component? Is there a simple way to communicate complex nuances these additional data create? Do we know the true impacts of all those additional assumptions when we increase the data requirements 100 fold but only supply 10x more data? Does model development happen independently or is there a self-sustaining strategic process?

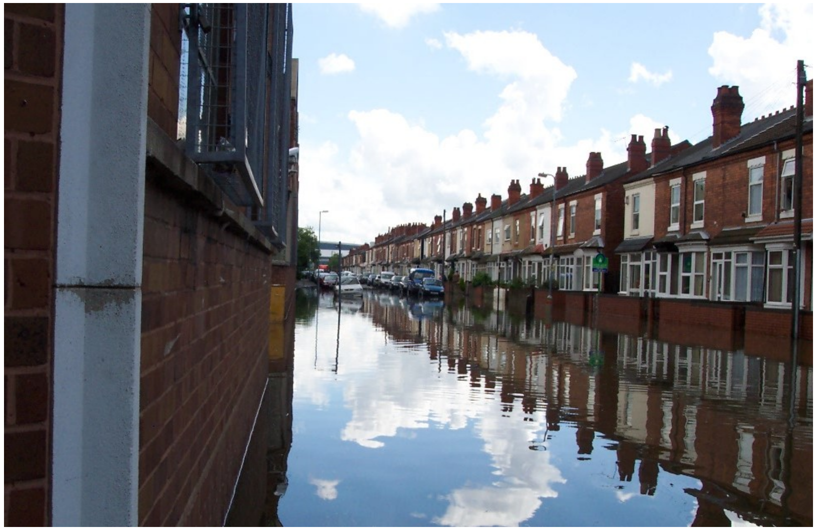
All-in-one modelling. Will we ever generate flood risk models that incorporate the entire environment? Computers are becoming more powerful, environmental sensors are invading our world, the internet knows where we are and what we are doing most of the time – data exists covering most aspects of our environment – can we ever combine and predict risk? We can observe, replicate and forecast many aspects of our environment – weather, habitats, sediments, structural deterioration, landscapes, population behaviour, etc. What is the value of combining all these disparate models into one? Can there be such thing as a combined risk modelling tool? Clearer understanding feedback loops and permutations of events and actions? Will there be any value in doing so? Who will it help?

Understanding Flood Risk



Development of integrated groundwater flood models. The winter 2013/2014 groundwater flooding has provided much new data that can be used to develop groundwater flood models. The Environment Agency has regional groundwater resources models for principle aquifers in England and a review is required of whether these can be adapted and calibrated to perform groundwater flood simulations or whether new models are needed. The aim is better mapping of groundwater flooding and understanding of the frequency and magnitude of groundwater flood events under current and future climate scenarios.





(Top) **Cockermouth 2009, (L)** Breach of the Cheshire lines Brook. The river overflowing into nearby fields. **(R) Flooded street, Witton 2007**

Managing Flood Probability

Working with Natural Processes - Catchment Laboratories. We know that natural approaches to flood management works in small catchments, we also know that these measures can benefit sediment management. However, current uptake of these types of measures has been slow. Although we have modelled evidence of their effectiveness, we are still at an early stage of collecting evidence to understand their actual flood risk benefits. There are specific areas of natural flood management which need further testing in the field. There are also funding and perception barriers which reduce the level of uptake of these schemes. To bridge some of these gaps we want to work with partners to set up 'catchment laboratories' to implement and test out natural approaches to flood management. This will build-upon the work of the DEFRA demonstration test catchments, and allow us and stakeholders to learn which natural flood management measures work, how effective are they in reducing flood risk and to undertake long-term monitoring of these measures. The laboratories would cover a range of spatial scales and a range of different catchments (urban, rural, coastal and estuarine). In rural locations we would want to test-out different land management measures, the effects of woody debris and grip blocking and look at effective ways of modelling sediment processes. In urban locations we would want to explore what natural approaches to flood management looks like in these locations and replacing hard engineered solutions with green engineering alternatives.

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 future 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 the decisions we take today don't leave future generations with expensive legacy infrastructure which has closed off many possible adaption strategies? How can we design today's infrastructure to transition to future change?

Understanding the benefits of routine maintenance. We are able to quantify the benefits and costs of building new flood defence scheme fairly easily, but our assessment of the likely benefits over the whole-life of the new assets and infrastructure are more difficult to get a handle on. Exploring how these benefit profiles change under different maintenance regimes and under different climate scenarios is harder still – in fact it is rarely done during the investment appraisal stages. We need to improve our understanding of how our assets and infrastructure (both built and natural) perform and deteriorate under differing management regimes and under possible future climates, so we can identify the optimal maintenance regimes given a fuller understanding of both the benefits and costs involved as well as viable remedial treatments.

Managing Flood Probability

How can we better adapt to long term climate related change on the coast? Climate change will lead to increases in average sea levels. Together with storm surge and other climate impact our coast line will evolve over the long term increasing the risk of coastal flooding and erosion in many locations. In some locations it will be no longer sustainable to either build new coastal protection structures or maintain existing ones. In these cases 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. inter-tidal habitats to help us mitigate flood and coastal erosion risk and help us adapt? How can we help communities understand, prepare for and manage this change? Scientists within the iCOASST project are helping to improve our prediction of long term, large scale geomorphic change on the coast and there is some good learning from the Coastal Change Pathfinders projects that can be built on.

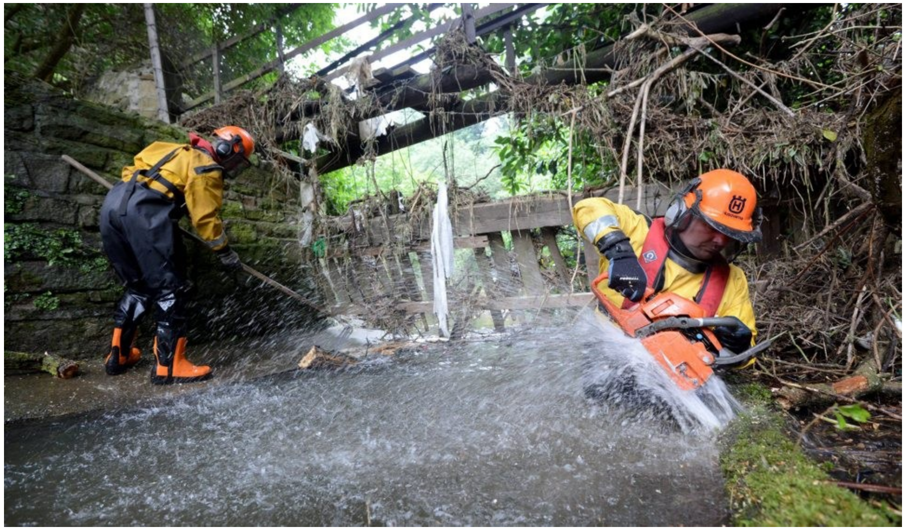
How can we better manage mixed beaches? The Environment Agency and Local Authorities reportedly spend over £20million annually on beach nourishment and management. Some beaches are predominantly shingle, some predominantly sand, both of which have good predictive tools. However, most beaches are mixed sand and shingle and there are no tools for these. How can we better predict the behaviour and response of mixed sand and shingle beaches? How does the behaviour of a mixed beach compare to a gravel beach? What empirical tools/ approaches can be developed to better understand design criteria for the nourishment of mixed beaches? How does particle size distribution influence sediment transport?

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 working period it may experience new extremes of rainfall, drought, heat and cold that were not anticipated when designed and constructed. How will the combinations of new extremes impact the potential failure modes of the UK's ageing stock of reservoirs? The long term effect of these extremes needs to be understood as well as the impacts of extremes coming together.

Managing the Consequence of Flooding

In the end it is all water, wind or mud – forecasting the impacts of flooding from any source and wider natural hazards. When you are affected by natural hazards, be it flooding, storm damage, landslides, you probably don't care that much about the exact source of the flood water or hazard but are more interested in the impacts and what you can do about it. With recent advancements in modelling and computing, the time is ripe to further integrate our approaches to forecasting flooding from *any source* and wider 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 ground water) and its impacts in real time. Maybe even a 'model of everything' from atmosphere, land, surface and water?

Crowdcasting – doing your bit to detect 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?



Environment Agency staff clearing a water course of debris following flooding in Lanchester, County Durham, ahead of forecasted torrential rain which was due to hit areas of the UK within a few days.

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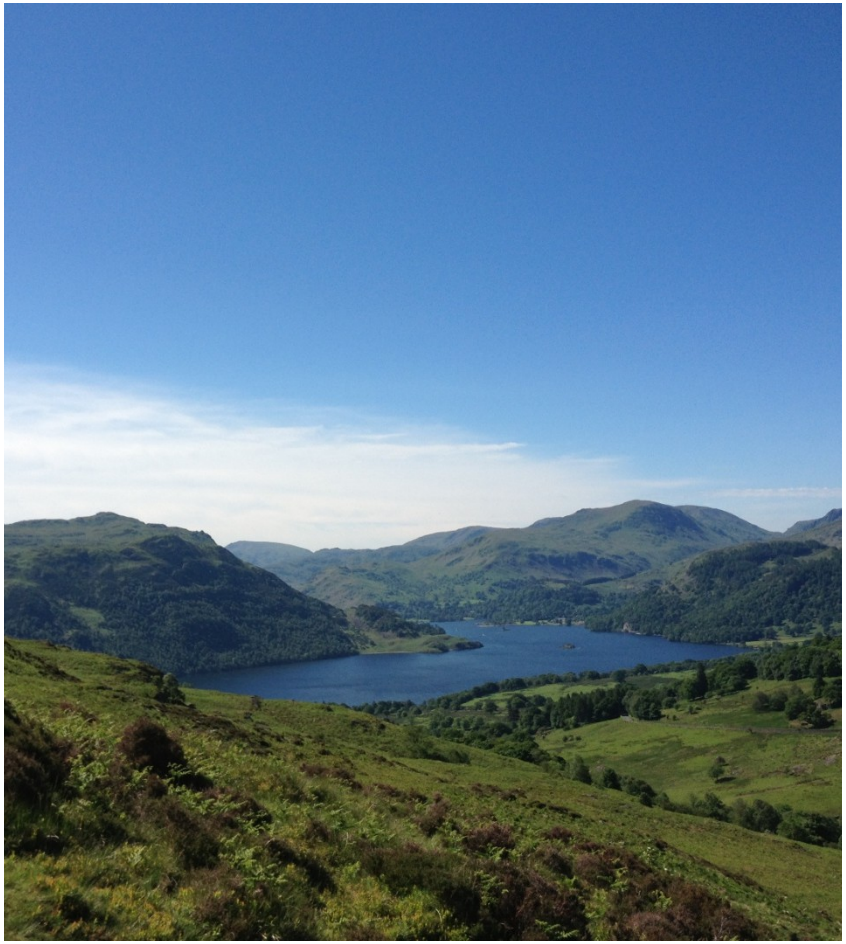
Climate change impacts and adaptation

Understanding 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. Sea-level rise will also change the incidence of coastal flooding as well as erosion and sedimentation patterns. Hydrohazards remain poorly understood, yet this is how many people will experience the impact of climate change. Hydrohazards include floods, droughts, poor water quality and soil erosion. 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.

Adaptation: what measures are needed and how can we make them happen? Despite an increasing understanding of climate change, adaptation remains patchy. Flood protection and water supply 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 to the uncertainties of future climate? How can we measure the effectiveness of adaptation and how much does it cost?



Ullswater

Environment Agency

Technology and innovation

Cost-effective monitoring of the environment. Measuring pressures and impacts in the environment is a key duty for the EA 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 reporting activities? And 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 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 air 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 habitats, land use, flooding, water quality (e.g. chlorophyll in surface waters) and other variables 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 regulators and environmental managers, including consideration of costs and handling the very large amounts of data generated.

V. **The internet of things.** We live in a time where your smart phone can link to your heating and your fridge might talk to your supermarket. But how could FCRM and Incident Management benefit from this wave of innovation? The possibilities and choices around the ‘internet of things’ and ‘sensorwebs’ are potentially huge - assets, flood gates, and other ‘things’ could automatically connect, talk to each other and take pre-emptive decisions during incidents. This could make FCRM management more responsive, interactive and more efficient. Could it be expanded to managing other activities like industrial emissions to air and water?

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 regular inspections. Getting underground is much more difficult. Some approaches do exist, such as ground penetrating radar or robots with video cameras. Usually these are only 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. And why wait until the water is underground? Our cities could 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, share, integrate, analyse and visualise. What systems will provide the services we need and how can they advance our 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. Since then, developments in nano materials have produced coatings that could make assets water proof or mould resistant. Scientists have also 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. It means they have no capacity left to drain surface water, leading to increased flooding. If the pipe is a combined sewer it can also cause sewage spills and increased costs to water companies. How could we reduce ground water infiltration? Digging up and replacing pipes is hugely expensive. Is it possible to fix the problem without digging up the pipes?

Cross-cutting research

Improving our economic evidence to support better 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 environmental 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 can we most effectively take 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 that are linked to the provision of ecosystem services.

Understanding the effectiveness of interventions and evaluating 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 at the scale of 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/or 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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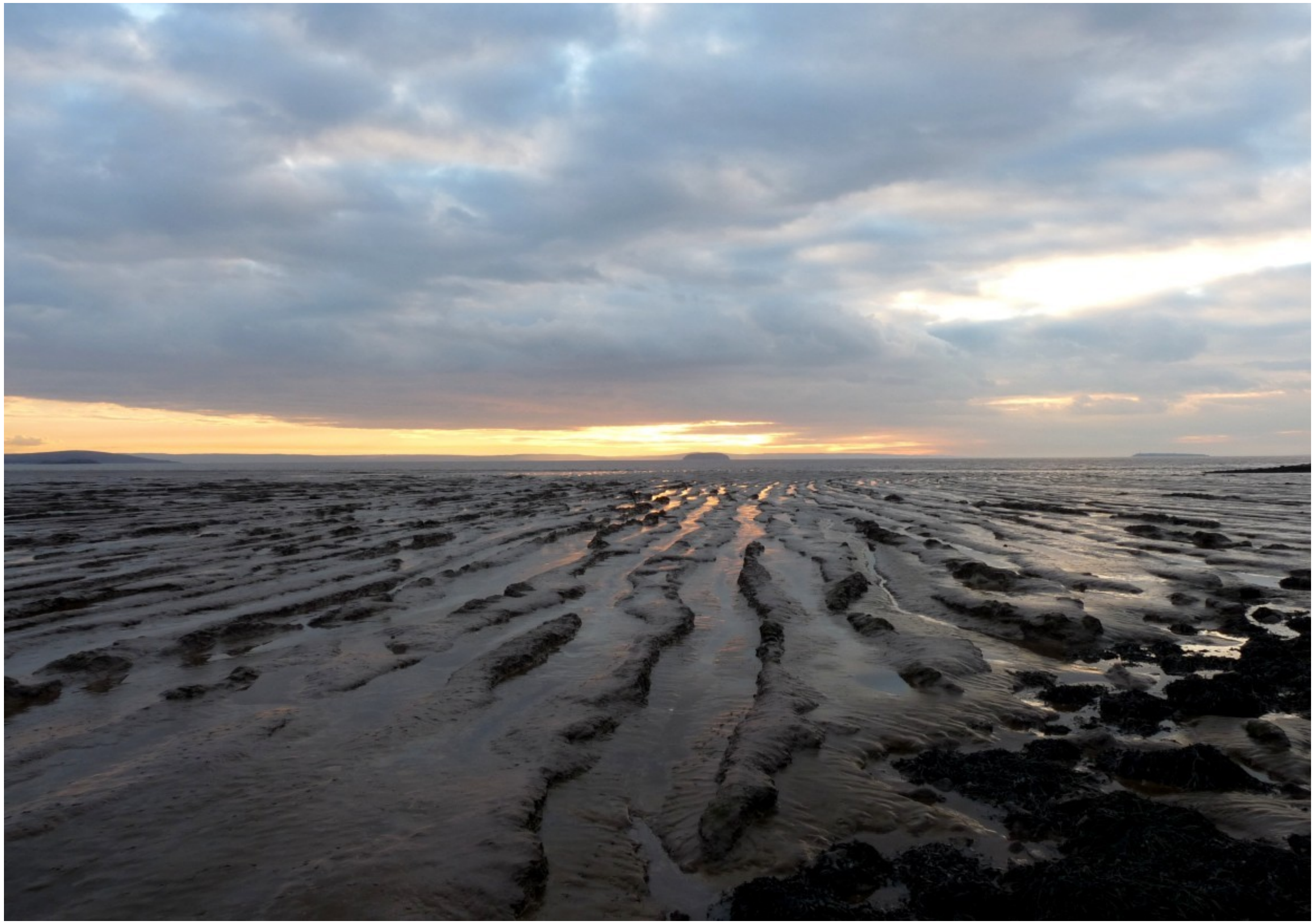

Mud flats in winter. Sand Bay, Weston-super-Mare, at dusk in February 2010.

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