



# FCERM Infrastructure Management and Performance (iMaP): Scoping a major new research initiative

## Report of the Research Development Workshop held on the 9<sup>th</sup> October 2014

A meeting organized with support of the ECI (University of Oxford), FCERM.net and the Environment Agency.

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## 1.0 Background to iMAP

iMAP aims to provide a significant programme of research (over 5 years) providing a new, richer, understanding of asset performance and how to manage asset systems efficiently and effectively.

The concept is that iMAP will be primarily funded through the research councils (subject to the normal peer review process) but shaped jointly by practitioners and researchers and co-funded by the Joint FCERM Science Programme<sup>1</sup> (data, in-kind and targeted funds).

Uniquely, the Joint R&D programme is providing funds to scope the programme of work, to ensure that it adequately represents the needs of users, is based on the latest scientific thinking and provides outputs which demonstrate research excellence and real world impact. In doing so, iMAP responds to challenge set out in the LWEC Strategy, including:

- The recognition of the importance of infrastructure and the need for innovative and transformative science to move practice forward.
- The need for a new way of developing and delivering research – co-developed and collaboratively delivered: cross-research councils, cross-discipline, push of excellence in science and the pull of practitioners.
- The benefits of interdependent science with a clear and ambitious line of sight to practice.
- The need to utilise co-working and common piloting by design not by chance.

### 1.1 Timeline

The iMAP submission will be developed over the coming months – including the identification of research activities, leading academics to act as Co-Investigators and industry partners.

It is likely to be submitted as a Programme Grant (to be confirmed). Assuming this is the case the submission process will consist of:

- A 2-page outline to be review by EPSRC and for EPSRC to formally give the go ahead to submit the next stage submission.
- A 4-page pre-submission to be accepted by the EPSRC and for EPSRC to formally give the go ahead to submit a full proposal.
- A full proposal to be submitted within 10 weeks of the go ahead from EPSRC. The full submission will then be Peer Reviewed.

Assuming all things proceed as planned the full submission to EPSRC will be around Spring 2015.

## 2.0 Supporting Rationale

In many places (in the UK and overseas) flood risk management continues to rely upon a broad range of flood defence assets to appropriately manage the probability of flooding. The sunk investment and on-going expenditure on both existing and potential future assets is significant (in the order of 70% of the overall Flood and Coastal Risk Management budget for England and Wales). Targeting this investment to best effect (maximising a wide range of benefits for multiple stakeholders) is not straightforward. Without improving our underlying science, actions may be poorly targeted; improving assets that do not need to be improved and leaving those that do. Without continuing to advance our scientific understanding and our ability to apply this understanding to national policy through to local individual asset management choices investments may be wasted and some risks left unmanaged.

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<sup>1</sup> <http://evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM.aspx> accessed 29/10/14

Whilst significant steps have been taken towards performance-based asset management (through initiatives such as FRMRC and the on-going activities under the Joint Programme), the necessary underpinning science to better plan, design and manage flood defences remains limited. The concept of asset systems has been embraced by the Agency but the ability to analyse the behaviour of all but the simplest of systems across multiple spatial and temporal scales remains out of reach. The temporal sequencing of storm events and deterioration, the spatial correlation in loading and asset properties (from crest levels to underlying geology) and the increasing need to proactively plan for future adaptation, multifunctionality and seek innovative funding mechanisms are all recognised challenges but practitioners have limited scientific support to draw upon. Equally, planning (appraisal), design and management continue, from an analysis perspective, to be considered separately and often with value-added understanding being lost between these key stages of the asset management lifecycle.

The need for more fundamental science was recently reinforced within the LWEC Floods Strategy<sup>2</sup>, CoRDDi<sup>3</sup> and the SAM TAG 5-year plan<sup>4</sup>. Each highlight the need for scientific innovations (made in collaboration with practitioners) if, in the longer term, asset management is to continue to become more efficient and deliver multi-functional performance and co-benefits.

Empirical evidence for the need to support continued research through iMaP also exists. For example, in the 2007 and 2012 storms floods defence assets performed well and better than existing analysis would suggest. This reinforces the belief that greater efficiency could be achieved if we knew more, and were confident in that knowledge.

The reality of funding is that asset managers are increasingly asked to do more with less; deliver multiple benefits with single actions and appropriately plan for future adaptation. iMaP will support asset managers and strategists (at national and local scales) in meeting these challenges, better justify expenditure and deliver more innovative, more efficient and better targeted actions.

### **3.0 Research Development Workshop**

Following an open call for Expressions of Interest, leading academics and practitioners were invited to a Research Development Workshop held on the 9<sup>th</sup> October at the ECI in Oxford. A summary of the workshop and its findings are outlined below.

#### **3.1 Aims of the Workshop**

The aim of the workshop was to co-identify (academics and practitioners) gaps, priorities and opportunities for innovative infrastructure related research, the most effective routes to uptake and candidate research topics.

#### **3.2 Agenda and Attendee list**

The Agenda and a list of attendees list is reproduced in Appendix 1.

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<sup>2</sup> <http://www.lwec.org.uk/our-work/uk-first-flood-research-strategy>

<sup>3</sup> <https://www.gov.uk/government/publications/a-framework-for-coastal-research-development-and-dissemination-corddi>

<sup>4</sup> [http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM\\_Documents/samworkplan.sflb.ashx](http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Documents/samworkplan.sflb.ashx)

### 3.3 Introductory presentations and discussions

A series of introductory presentations were provided by Paul Sayers, Jim Hall and Andy Moores. These outlined the aims and objectives of the day and the rationale behind iMAP and are reproduced in Appendix 2.

The Plenary discussion that followed these presentations provided an opportunity to explore/confirm the scope of iMAP and the definition of ‘infrastructure’. It was confirmed that the scope of iMAP encompassed *any activities that influence the planning, design or management of physical infrastructure* (i.e. social issues, engineering issues, multi-functional assets etc). In this context, physical infrastructure was broadly defined as included *hard* (walls etc) and *soft* (beaches, channels etc), *system scale* and *point scale* (from the Thames Barrier to property level property).

This initial plenary session also set the tone for the day in highlighting a number of key gaps and issues, confirming the need to:

- Make a step change in our understanding of how assets perform; both individually and as systems.
- Better recognize the reality of the loading conditions faced; including sequences of events and large (spatially coherent) flood events (rather than single design events).
- Better understand the interaction between human systems and their role in managing assets (both active assets such as barriers and gates, as well as maintaining / inspecting passive structures such as embankments).
- Develop optimum solutions that target investment more wisely.
- Make better use of lower cost more pervasive monitoring techniques to gather performance information in real-time.

### 3.4 Group discussions

The attendees were divided into four equal self-selected groups. Each Group was then asked to discuss the research opportunities and needs in four areas:

- Transforming our understanding of performance
- Disrupting design practice - Adaptive and resilient
- Making better investment choices at multi-scales
- Transforming real-time infrastructure management and performance forecasts

*Note:* Significant research into hydrodynamic modelling (i.e. inundation modelling) is not within the scope of iMAP unless a clear connection with the themes above can be demonstrated. This was a constraint recognised as appropriate by the attendees.

A summary of the Group discussions is given below. Verbatim copies of the workshop flip charts (created by each Group) are provided in Appendix 3.

#### 3.4.1 Transforming our understanding of performance

The research areas and potential opportunities highlighted by the Groups included:

- *Moving from a design standards based approach to a time dependent reliability based approach* – this will demand a deeper understanding of reliability (much closer to reality at asset transitions and for heterogeneous structures) and changes in time through deterioration.

- *Exploiting new techniques for monitoring and observations* (i) both short and longer term – making use of pervasive ‘cheap’ sensors alongside traditional techniques (ii) use of reach vs point based condition assessment (iii) better understanding of critical weaknesses and defence discontinuities (iv) exploitation of BIG DATA (integrating informal and formal data).  
Understanding the costs and benefits of increased monitoring (optimising monitoring based on risk)
- *Understanding multiple asset Interactions* – between an individual asset and the asset system (ii) between the physical infrastructure and (a) human operators (b) the communities protected (c) the broader ecosystems the assets form part of.
- *The characterization of loading* - moving towards sensible ensembles for design – sequences of events - and away from a single design event.
- *Recoverability and deterioration* – the ability of natural systems to recover / tipping points and the progressive process and rate of deterioration of engineered assets. Enhance our ability to explore component/process based deterioration and understand the contribution of asset elements to risk).
- *Validation and calibration of approaches* - better validation / calibration of Condition Assessment processes. Evidence from past failures and near misses may provide a better understanding between ‘condition’ and ‘performance’.
- *Bringing together an assessment and an analysis of performance* that is based on (i) multiple failure modes (ii) uses multiple data sources, and (iii) recognizes the multiple loading conditions.

#### **General points from the Plenary session based on the Group discussions**

- *The performance of assets coupled with community resilience* – i.e. risk reduction through coherent community.
- *Active structures* – comparing risk of non-closure with failure.
- *The real impact of maintenance on flood likelihood.*
- *Scenario discovery to feed into complex modelling.*
- *Infrastructure analytics* – a more structured science based approach to information provision.

### **3.4.2 Disrupting design practice - Adaptive and resilient**

The research areas and potential opportunities highlighted by the Groups included:

- *What does adaptation look like* – what is a good adaptive design (structural form, the materials, the construction method, the relationship with natural processes)?
- *What do flexible designs and practical adaptive decision pathways look like* - are they achievable beyond very basic responses.
- *Adaptive capacity is inherent in natural systems – but not in engineered systems* – can engineered systems better mimic these attributes? For example use of actuators, self-healing materials, maximising the benefits from working within natural processes?
- *Does material science offer opportunities to support adaptive design?*

- *Opportunities for large scale geo-engineering* - modifying system performance through geoengineering – ‘sand pump’, coastal morphology, storage etc. The promotion of ecosystem approaches and ecosystems as legitimate FCERM infrastructure.
- *Develop a meaningful and new narrative to express uncertainty* – design uncertainty vs environment uncertainty (performance vs env loading and moving away from ‘freeboard’ towards a ‘residual uncertainty allowance’ as currently being promoted within the update to the Freeboard Guide<sup>5</sup>)
- *Tolerable risks / acceptable performance* – what role this has, what are they and how can they be formalized?
- *Trade-offs* – resilience (ultimate limit states and serviceability limit states), the dynamic nature of natural systems (and their ability to ‘recover’ and adapt) v the static of fixed engineering structures (and their limited ability to be adapted and repaired); costs and potential for partnership funding, security of performance, local adaptation, benefits etc
- *How to challenge the status quo* - Avoiding like-for-like replacements, promoting adaptive designs.

#### **General points from the Plenary session based on the Group discussions**

- Promoting an ability for ‘living with dynamic infrastructure systems’.
- Recognize that the planning process is adaptive – not just the design.
- Promote recovery as well as adaptation.
- Incorporate people and the reality of community activities into the design process – seek innovative / good practice ways of managing the erosion of creates by walkers and cattle.
- Getting the semantics right – important for making progress.
- Community influence on design.
- Delivering multifunctional use of assets.
- Need to remember that majority of FCERM assets already exist – retrofitting the asset stock will be increasingly significant.

### **3.4.3 Making better investment choices at multi-scales**

The research areas and potential opportunities highlighted by the Groups included:

- *What are the choices we are making:* (i) Understanding the multi expressions of desirable outcomes, (ii) the spatial relationship between choices (local-catchment–national) – recognizing at different scales the criteria will also change.
- *Delivering more for less through economies of scale* (i) multi-actor involvement – making the partnership funding work (ii) large scale protection is expensive – house by house property is cheap?
- *Decision analysis techniques* – incorporating time sequencing and system memory within the decision framework (such as spending less today may reduce capacity to act in later years, as well as physical time dependent changes in the asset base, loading, deterioration etc)

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<sup>5</sup> <http://www.sayersandpartners.co.uk/freeboard.html>

- *Incorporating secondary (cascading hazards) and interdependences within the infrastructure networks affected.*
- *Promoting multi functionality and multi-use is likely to cost more – are the additional benefits worth it, who pays and how can it be made to work?*
- *Does the basis of the loss estimate match the basis of management of the risk – local losses v UK plc, economic v financial?*
- *'hydrosystem services approach' - Provide a whole system assessment of the risks and opportunities – economic, environment, social; national and local benefits appropriately balanced; presenting monetized and non-monetized risks*
- *How do we know when a decision is better – constructing meaningful conceptual frameworks and pilot sites for testing new approaches.*
- *Need for simplifying complex issues – a simple dashboard to enable users to explore trade-offs complex portfolios of response in a comprehensive manner. This should embed (i) search and optimization approaches; (ii) serious gaming techniques; (ii) scenario approaches.*
  - *Innovation in procurement approaches – appropriate scales and arrangements that promote innovative and multi benefits (for example learning lessons from the Thames Estuary large scale / single procurement). Noting that the focus here is on the scientific justification of alteration of procurement strategies not the mechanics of the procurement process.*
- *Multi-actor/multi-agent choices - the landscape in which FCERM is delivered is trying to change (EA, Partnership funding, resilience, tolerability, adaptive, risks and opportunities, multiple responses organized into complex portfolios). How can this transition be supported?*
- *Ability to explore alternative business models for flood defence – for example a privatization model of Dieter Helm? Can major shared functions be delivered – energy generation and flood management?*
- *How to optimize large scale investments – to support social justice, equity and benefit cost tests. Is it better to fund many local ones or a few major scale?*

***General points from the Plenary session based on the Group discussions***

- Optimization of revenue and capital expenditure (as infrastructure providers move towards a 'totex' decision basis), insurance activities, partnership funds etc
- Trade off curves across multiple parameters + tools to make sense of this for decision makers
- Bridging the disconnect between LTIS Medium term plan and annual investment portfolio
- Uncertainty – how can all forms of uncertainty be suitably handled and progressively understood (in data, model and severe uncertainties in future change)
- Borrowing portfolio planning tools from financial services – time sequencing and propagation of investment choices through broader economy
- Matching timescale of decision needs to model timescales

**3.4.4 Transforming real-time infrastructure management and performance forecasts**

The research areas and potential opportunities highlighted by the Groups included:



- *Towards flood risk forecasts* – current systems are typically simple estimates of river / coastal levels, overflows/overtopping assuming perfect defences and basic inundation. Opportunities exist to incorporate asset performance to provide more realistic and credible forecasts including breach, blockage, failure to operate etc.
- *Use of smart monitoring to inform asset performance models in real time* – building upon initiatives such as UrbanFlood for example
- *Agent based evacuation (of people) modelling* – using flood systems that incorporate asset performance to explore the potential evacuation and develop better / richer rule sets for important behaviours – can this be used to provide real time advice as well as planning advice?
- *Calibration of breach likelihood from empirical evidence* – the belief that current fragility information continues to overstate breach likelihood persists. Is this perception true?
- *Event atlas* – detailed forensics from real events could be used to form the basis of undertaking the performance of ‘models’ beyond inundation extents/depths/velocities.
- *Real time optimisation of resource deployment* – where should resources be deployed, what equipment is needed, who should be prioritised (taking account of the likely behaviour of the assets, vulnerabilities etc). Identifying weakest links in asset / asset systems in real time to direct operational teams.
- *More towards ‘Anticipatory Incident Management’* – using short term, seasonal and decadal forecasts (including asset performance models) to prepare better for foreseeable incidents.

#### **General points from the Plenary session based on the Group discussions**

- Non-supervised learning environments may provide an opportunity for improved system modelling (i.e. data based approaches)
- Support to major piloting – for example in support of flood response exercises

### **3.5 Summary of reflections on the Group discussions**

**So, the design event is dead, but where do we move to next?** Performance of flood and erosion risk infrastructure, at both the individual asset and system level, under storm sequences was a reoccurring topic across the four themes. There was a wide acceptance that the concept of the design event was no longer fit for purpose. There is a clear need to better understand the evolution of asset performance throughout a sequence of events and to understand the resilience of infrastructure systems to repeat shocks. In addition expenditure should be optimised on the ability of infrastructure to resist and recover from repeat event. The same logic can be applied to include infrastructure resilience to widespread flooding and multivariate extremes.

**How can we best maximise the benefits from pervasive monitoring?** Relatively cheap monitoring technologies which could be deployed rapidly and widely are becoming increasingly available. Such technologies could afford opportunities to monitor performance in real-time.

**How can we formalise informal observations?** How can we formalise informal crowd sourced information and data to improved infrastructure operations? What is the potential to use crowd

sourced information to monitor performance during events? Research to answer such questions could include novel statistical methods for analysing incomplete datasets. As well as, social science to help understand strengths and weakness of these data and the information that can usefully be generated from such data.

**How effective could a local infrastructure delivery model be?** How could FCRM be delivered at a local level, would such a business model be more resilient than centralised delivery? The topic of business models were discussed more under the ‘optimisation’ theme. Research could usefully be done to identify optimum business models for whole-life FCRM infrastructure management. Current business models perhaps focus too much on capital investment and don’t adequately take account of the needs of continued maintenance, adaptation and decommissioning.

**How are the impacts of infrastructure failure felt across the country?** Losses due to infrastructure failure are felt differently as the ‘ripples of impact’ propagate through local, regional and national economies. Similarly, infrastructure investment priorities differ when viewed from these standpoints. An improved understanding of how different events may lead to different losses at these spatial scales would be useful would aid prioritisation and delivery.

**Can we define and quantify resilience and adaptability?** In typical workshop fashion the definitions of the terms resilience and adaptability were discussed. Views differed particularly with regard to the terms that are/could be included in “resilience”. There was some broad agreement that resilient infrastructure would be engineered and natural systems that were able to anticipate, resist, recover from and adapt to, repeat shocks. Research to define infrastructure resilience formally, and to develop a single metric by which resilience could be quantified would be useful.

**How do we adapt existing/legacy infrastructure?** The workshop highlighted that not much greenfield design would take place, and so the real issue would be how to best adapt our existing infrastructure. The barriers to adaption and perverse incentives against adapting are numerous and include, but are not limited to: availability of space, conflicting legislation, indemnity insurance, uncertainty, social acceptability.

**Innovation in adaption.** What is the scope for the identification of new or the reuse novel materials which enhance the adaptive capacity and/or resilience of FCRM infrastructure? How can we move to more dynamic systems which evolve on their own accord without compromising reliability? How can we truly optimise across the complete portfolio if FCRM Infrastructure and dependant systems? To date even our best attempts at optimisation only analyses a small portion of the FCRM infrastructure system and rarely (if at all) account for any of the supporting and interacting systems. Can we move forward to a position where we can truly optimise decisions over the FCRM portfolio? Where and when will be the critical tipping points for our FCERM infrastructure systems? Some analysis effort was spent on TE2100 (the project that set out the strategy for managing flood risk in the Thames Estuary through to 2100) to explore when key decisions needed to be made on the several options for managing risk to London and the tidal Thames. This analysis usefully helped define the outer envelope of change to which we could engineer – the so called, “limits of engineering adaption”. Are there similar limits which could be defined for other estuaries and coasts as well as for fluvial situations?

## 4.0 Emergent research themes

During the final plenary session of the day the shape of the iMAP proposal started to emerge and the original 4 discussion themes were recast to better represent the identified synergies between topics. Based on the discussions an initial framework of research started to take shape. Although

this will continue to develop in the coming months (and is likely to be further rationalized to limit the number of work packages) the emerging structure is as follows:

#### **4.1 Work Package #1 - Infrastructure informatics**

Focusing on innovations within the sensing and processing communities with a view to developing new and novel approaches relevant to infrastructure management.

This could include research associated with:

- Sensing
- Sourcing
- Processing

A key focus here would be on informatics that support multiple timescales: real time to long term

#### **4.2 Work Package #2 - Asset performance**

Focusing on how individual assets and asset systems behave, with a particular emphasis on advances in approaches in reliability and deterioration.

#### **4.3 Work Package #3 – System risks and attribution**

Focusing on providing multi-scale (in space and time – from real time to long term) whole system risk models approaches that formally capture uncertainties (data, model and model structure).

#### **4.4 Work Package #4 - Optimisation**

Focusing on providing powerful search tools to help identify optimal portfolios of actions that are:

- Multi-objective
- Multi-actor

The approaches should capture the reality and complexity of the decision process. They should be capable of application under conditions of uncertainty and changing business models for adaptability and resilience.

#### **4.5 Work Package #5 - Multi-purpose infrastructure analytics**

A decision dash board targeting a range of Users and Timescales – ‘long term planning’ through to ‘Anticipatory Incident Management’

#### **4.6 Work Package #6 – Pilot and System Observatories**

Focusing on providing a test bed for focusing effort and testing new approaches in a well instrumented, data rich environment. Link to major initiatives – e.g. next generation LTIS, Operation Water Mark as well as the identification of a real asset management system as a testbed.

#### **4.7 Work Package #7 – Engagement and dissemination**

Engaging practitioners within the research and, in selected areas, providing specific outputs focused at shorter term user needs.

## 5.0 Next Steps

There was overwhelming support for iMAP in terms of both the research need and the concept of a co-developed co-funded initiative. The focus on flood related infrastructure was considered timely and of critical importance to both the UK and internationally.

Given this confirmation of support the next steps will be:

### 5.1 For Paul and Jim

- to develop a two-page outline for submission to EPSRC (by the end of Nov 2014)
- following discussion with EPSRC submit a four page outline for internal review by the EPSRC (by the end of Jan 2015). This will include main themes and team
- submit a full proposal within 10 weeks of getting the green light from EPSRC.

### 5.2 For all those interested in iMAP

If, following the workshop, you are interested in pursuing an involvement in iMAP further, can you please:

- submit a short 1 page description of the contribution they could make to iMAP together with your publication track record in that area. The suggestions should be targeted at one or more of the Work Packages identified in Chapter 4 above (or alternative work packages with associated justification). Submissions should not be full standalone 'bids' but suggested research activities that could be appropriately shaped as part of an overall iMAP suggestion. **Please email your suggestions to [paul.sayers@ouce.ox.ac.uk](mailto:paul.sayers@ouce.ox.ac.uk) and [jim.hall@ouce.ox.co.uk](mailto:jim.hall@ouce.ox.co.uk) by the 14<sup>th</sup> November.**

### 5.3 Final note

A **big thank you** to all those that attended the workshop and contributed so openly and to ECI support team for making the day run so smoothly.

As discussed during the workshop, iMAP will be a competitive submission to EPSRC. iMAP must be a focused submission and link the 'best with the best'. This inevitably means that not all those attending the workshop will be involved, and others not at the workshop will be. However, for those not involved in iMAP, and the areas of research not taken forward, this is not necessarily the end. These workshop notes will be circulated amongst the Theme Leaders within the Joint Programme and hopefully opportunities to take them forward outside of iMAP will present themselves either via further programmes of work or as standalone bids into responsive mode Research Council funding.

## **Appendices**

### **Appendix 1: Agenda and attendee list**

See separate file

### **Appendix 2: Introductory presentations**

See separate file

### **Appendix 3: Transcripts of the Group flip charts**

See separate file