Department for Environment Food & Rural Affairs

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Environment Agency

delivering benefits through evidence

Quantifying the benefits of Flood and Coastal Erosion Risk Management

Stakeholder and community engagement and modelling, mapping and data

Report – SC130008/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

We are the Environment Agency. We protect and improve the environment and make it a better place for people and wildlife.

We operate at the place where environmental change has its greatest impact on people's lives. We reduce the risks to people and properties from flooding; make sure there is enough water for people and wildlife; protect and improve air, land and water quality and apply the environmental standards within which industry can operate.

Acting to reduce climate change and helping people and wildlife adapt to its consequences are at the heart of all that we do.

We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

This report is the result of research commissioned by the Environment Agency's Evidence Directorate and funded by the joint Flood and Coastal Erosion Risk Management Research and Development Programme.

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Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

This report was produced by the Scientific and Evidence Services team within Evidence. The team focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
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- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Executive summary

Aim of the project

The Environment Agency needs to be able to transparently determine and quantify the contributions made by its Modelling, Mapping and Data (MMD) and Stakeholder and Community Engagement (SCE) teams to flood and coastal erosion risk management (FCERM) outcomes.

This project has trialled the use of dependency modelling to establish whether it can provide a clear and evidence based explanation of how MMD and SCE activities contribute to FCERM outcomes. This would:

- help the Environment Agency communicate how these activities contribute to improved outcomes
- help senior managers understand how changes in resource allocation could affect achievement of these outcomes
- help identify where more effective or efficient ways of carrying out activities and realising outcomes could achieve better value for money

This report presents the findings of this project. It introduces the concept of dependency modelling, describes the methodology used and presents the outputs of the dependency modelling process.

Approach

The dependency modelling was carried out using a highly participatory workshop-led approach involving three basic steps:

- identifying outcome measures that are most relevant
- identifying influences that affect these outcome measures
- quantifying the importance of the cause and effect relationships

Findings

The project has demonstrated that the dependency modelling approach is useful in the FCERM field. It has helped those involved in developing the models to understand

- the complex relationships between FCERM activities and outcomes
- how the models can be used to help communicate and then quantify these relationships

Qualitative models have been produced for both MMD and SCE. These models help illustrate the activities undertaken by these Environment Agency teams and how they contribute to important FCERM outcomes. The qualitative models have already been used to help explain the role of the MMD teams and how the activities they carry out are critical in achieving FCERM outcomes.

The project has also developed quantitative models for both MMD and SCE. Although the models developed at this stage are simple, they demonstrate how the approach can be used to identify the activities that contribute most to outputs.

The SCE model has shown that, in communities where there has not been recent engagement or have not previously been affected by flooding, without investing in engagement improvements there are unlikely to be improvements in:

- the development and implementation of the capital and maintenance programmes
- flood warnings or community awareness and action
- customer enquiries and complaints

Improving the specific community engagement planning activity results in the greatest improvements to the outputs listed above.

The process of developing the models is often as valuable to the participants as the end product. In this project, the participants found it very helpful to articulate their activities and the outcomes using dependency maps.

The models are being developed further by the Environment Agency for use in the 2015 Spending Review, emphasising that this approach has been successfully adopted as a means of articulating the complex structure of FCERM.

Recommendations

1. The qualitative maps are of considerable benefit. MMD and SCE staff should continue to develop them as ‘live’ documents to help them communicate widely within the Environment Agency and externally how their activities contribute to flood and coastal erosion risk management outcomes.
2. The approach outlined above is a viable way of quantifying the benefit of SCE and MMD activities. The Environment Agency should continue to improve the quantitative models developed during the project by:
    - consulting more widely to add detail to the models and refine the node probability estimates
    - gathering cost and benefit data to make use of the cost–benefit assessment capabilities of the software
3. The journey for the participants is just as valuable as the end models. Other Environment Agency teams should adopt this approach to understand how their activities contribute to Environment Agency outcomes.
4. An early stage in developing the quantified models includes a structured exercise focused on identifying potential improvements to achieve better outcomes. Model development should be taken at least to this stage in each case if full quantification cannot be achieved.

Acknowledgements

This work was led by a team from Risk Solutions, DecisionLab and IPL. The models, however, were developed and quantified by Environment Agency stakeholder and community engagement (SCE) and modelling, mapping and data (MMD) practitioners and their colleagues (listed below). We would like to thank them for their enthusiastic and expert participation throughout the project. We would particularly like to thank our Environment Agency project manager Lydia Burgess-Gamble, who was instrumental in ensuring the success of this engagement.

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1 Introduction

1.1 Background and objectives

The Environment Agency needs a methodology to demonstrate and quantify how its modelling, mapping and data (MMD) and stakeholder and community engagement (SCE) activities contribute to the achievement of Flood and Coastal Erosion Risk Management (FCERM) outcomes.

Dependency modelling was proposed by the Environment Agency as a suitable modelling approach to achieve this based on its past use to quantify waste management activities. The Environment Agency therefore contracted Risk Solutions, DecisionLab and IPL to help it develop a set of dependency models that could be used to:

- provide a clear and evidence based explanation of how MMD and SCE activities contribute to FCERM outcomes
- enable senior managers to understand how changes in resource allocation could affect achievement of these outcomes
- help identify where more effective or efficient ways of carrying out activities and achieving outcomes could provide better value for money

1.2 Project outputs

The project produced the following outputs:

- **Inception report** supported by a detailed Microsoft® PowerPoint presentation:
    - summarises the research into dependency modelling
    - describes the recommended methodology
    - reviews the available software tools
    - recommends which to consider for the project
- **Research report** (this document) – this describes:
    - the work undertaken
    - the dependency models
    - the initial analyses carried out using them
    - recommendations for their further development
- **Research summary** – a two-page summary of this report
- **Dependency models** – coded in the DPL software package

1.3 Structure of this report

Section 2 introduces dependency modelling.

Section 3 briefly describes the methodology adopted to build and quantify the models.

Section 4 describes the FCERM outcomes used to ‘anchor’ the discussions during the project and to structure the models.

Sections 5 and 6 describe the qualitative and quantitative models respectively.

Section 7 summarises the conclusions and Section 8 provides recommendations.

2 Dependency modelling

2.1 Introduction

Dependency models are a way of representing a real system in order to understand cause and effect relationships. They may also be called influence diagrams, Bayesian (belief) networks, directed graphical models or causal probabilistic models.

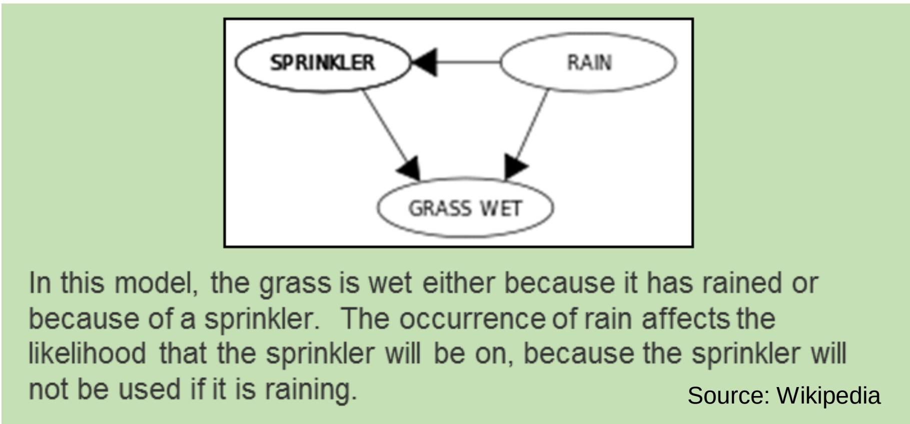
Dependency models are used to support complex decision making in situations where cause and effect relationships are uncertain. They can be used to:

- find the probability of achieving outcomes
- quantify the impact on the probability of achieving outcomes when changing elements within the system

The models can therefore be used to:

- find the dependencies that are most pivotal to success
- find the most likely causes of success and failure
- find the most critical uncertainties
- quantify and measure the risk to achieving outcomes, and find ways to reduce it
- find the best ways to deploy resources for maximum benefit

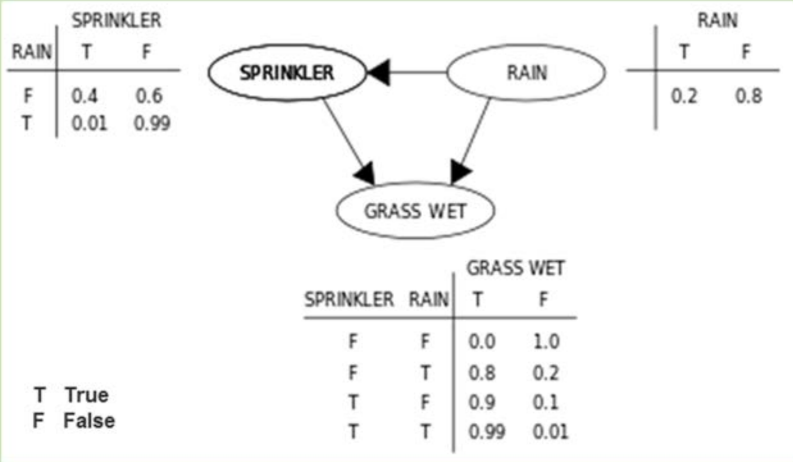
Dependency models use a symbolic network to represent the connections and influences in a system. This can be combined with statistical techniques (for example, probability distributions) to model uncertainty. Figure 2.1 shows the structure of a simple dependency model.



Source: Wikipedia

Figure 2.1 A simple dependency model – the causes of wet grass

Dependency models deal in probabilities. The underlying network structure is used to calculate the probability that certain events will occur and how these probabilities will change given subsequent observations or a set of external (for example, management) interventions. They are able to capture the existence of conditional probabilities – where the chance or likelihood of an event happening depends on whether or not some other events in the system have happened. Figure 2.2 shows the probability tables associated with the wet grass model, that is, what is the probability that the grass will be wet in the morning.



The probability table at the top right shows that there is a 20% chance of rain. The conditional probability table at the top left shows the probability of the sprinkler being on, given that it is either raining or not. In this case, if it is raining, the sprinkler has a 1% chance of being on, and a 40% chance if it is not raining (hence *conditional*). The conditional probability table at the bottom indicates the chance that the grass will be wet, given the states of rain and sprinkler. For example, there is a 99% chance that the grass will be wet if it is raining and the sprinkler is on.

Figure 2.2 The wet grass model showing the probability tables

The mathematics underpinning dependency models is grounded in well-established probability theories such as Bayes' theorem, which provides a method for updating probabilities based on new information or assumptions. Dependency modelling software takes care of the mathematics and allows model users to focus their efforts on the assumptions and relationships captured within the network.

2.2 Example of use

No published work relating specifically to the mapping of organisational activities to environmental outcomes was found. Although there is at least one model currently being developed that maps organisational activities to environmental outcomes (Fenton N, personal communication, 2014[1]), details of this work are not currently available. However, dependency modelling has been previously successfully used, separately, in both environmental decision contexts and to map organisational activities to outcomes in other areas. They have been applied to a range of practical fields including ecology, medicine, law, finance, engineering, safety and information technology (IT).

Figure 2.3 illustrates a case study on greenhouse gas management.

[1] Professor Norman Fenton is director of the Risk and Information Management Research Group, Queen Mary University of London and author of *Risk Assessment and Decision Analysis with Bayesian Networks* (2013).

Dependency model to manage greenhouse gas (GHG) emissions in the British agricultural sector

Situation

Existing GHG models were confusing due to uncertainties and complex variable interdependencies.

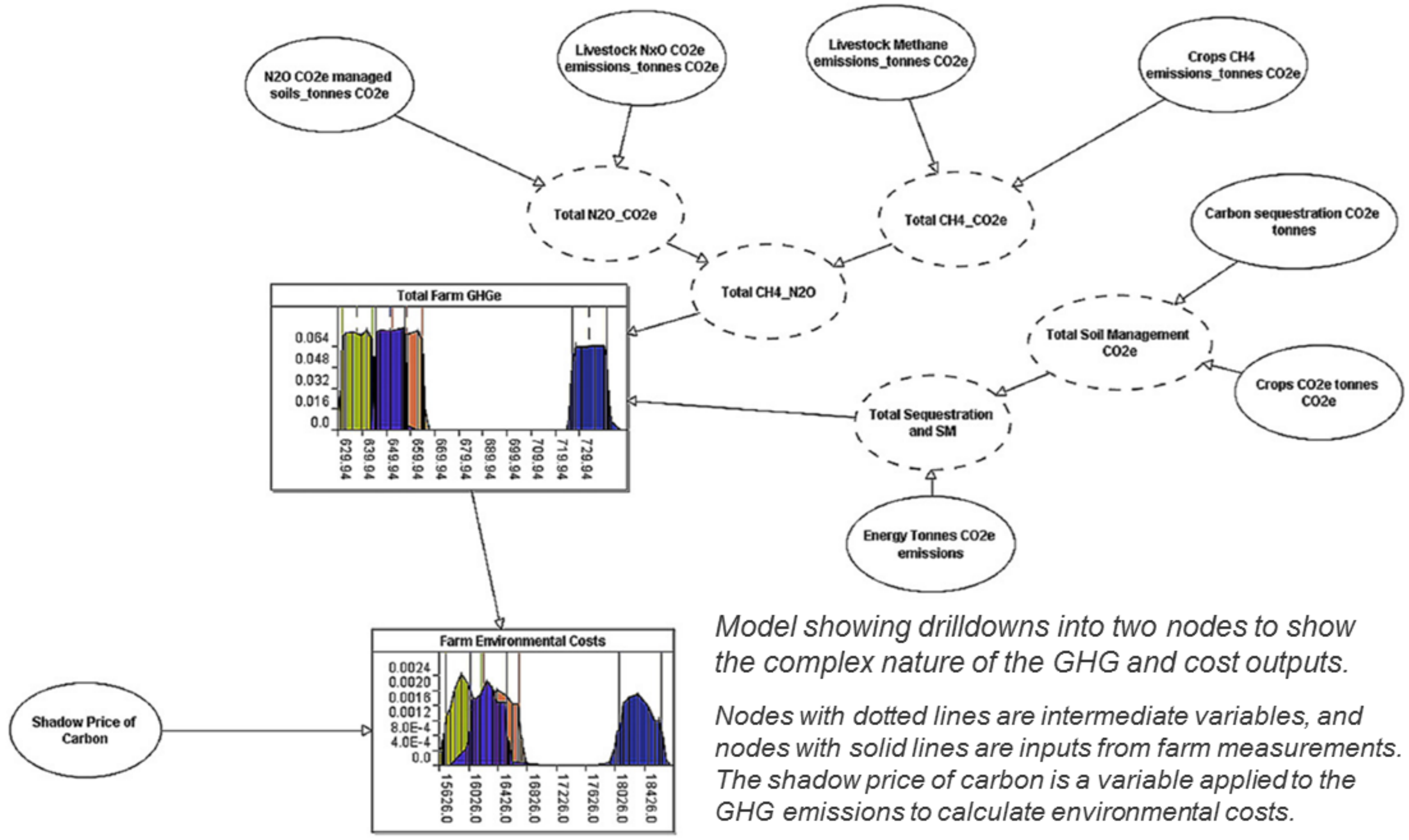
Objective

Build a dependency model to handle uncertainties and clearly communicate the impact of GHG emissions.

Dependency model

The model (right) is an interconnected network with some variables being continuous. It is reasonably complex in nature. Key features to note:

- The model estimates the annual GHG emissions of a British farm.
- The model uses probabilistic inputs (existing models are deterministic), so risk and uncertainty are estimated more reliably.
- The model can be used with a measurement tool with both discrete and continuous inputs.
- It can investigate a range of interventions.
- It can be extended to include economic risks and benefits.



Model showing drilldowns into two nodes to show the complex nature of the GHG and cost outputs.

Nodes with dotted lines are intermediate variables, and nodes with solid lines are inputs from farm measurements. The shadow price of carbon is a variable applied to the GHG emissions to calculate environmental costs.

Results

When combined with an existing measurement tool, this dependency model provides two results:

- A set of interventions were identified which can reduce GHG emissions by 25% on any particular farm.
- A farm can have a greater impact on its carbon footprint through land and livestock management practices than through a reduction of its energy consumption or replacing the energy supply.

Feedback from the farming community has been positive.

Figure 2.3 Case study: use of dependency modelling in greenhouse gas management

Source: Pérez-Miñana et al. 2012

2.3 Strengths and limitations

Table 2.1 summarises the strengths and limitations of dependency models.

Table 2.1 Strengths and limitations of dependency models

Strengths	Limitations
Can investigate the impact of multiple factors on multiple outcomes in a complex environment.	Constructing the network architecture can be a complex problem.
Can use information from different sources and can combine evidence with subjective expert judgement.	Dependency models cannot handle loops/cycles (could use simulation instead).
Can handle missing data – predictions can be made with incomplete datasets by propagating partial information through the network.	Models have limited ability to handle continuous data such as cost and rainfall (depends on software used).
Can explicitly quantify uncertainty through probability distributions.	Large-scale models can become unwieldy and lose accuracy.
Has a simple, intuitive, flexible graphical structure and is a powerful tool for communicating and understanding.	
Models are transparent – relationships are made explicit and not hidden.	
Finished models provide a language to discuss risk and complex cause–effect dependencies.	
Models require clear articulation of the intended outcomes; **hence differences of understanding are more likely to be uncovered.**	

2.4 Why use dependency modelling for this project

This project involved modelling a system with the following four important features.

1. The outcomes of interest are relatively easy to articulate in broad terms, but more difficult to define precisely.
2. The overall structure of the system is relatively simple (see Figure 2.4). However, the dependence of outcomes on activities can be complex and often indirect (for example, modelling enables flood damage reduction activities to be directed to areas of most need, but does not reduce damage directly). The two

areas of interest to the Environment Agency (MMD and SCE) will have more or less direct impact on the outcomes of interest depending on a range of factors.

3. There are only limited data available to help link activities to outcomes. Expert input is required to link them and to quantify these links.
4. The outputs of the modelling needs to be understood within the broader context of well-defined decision-making processes.

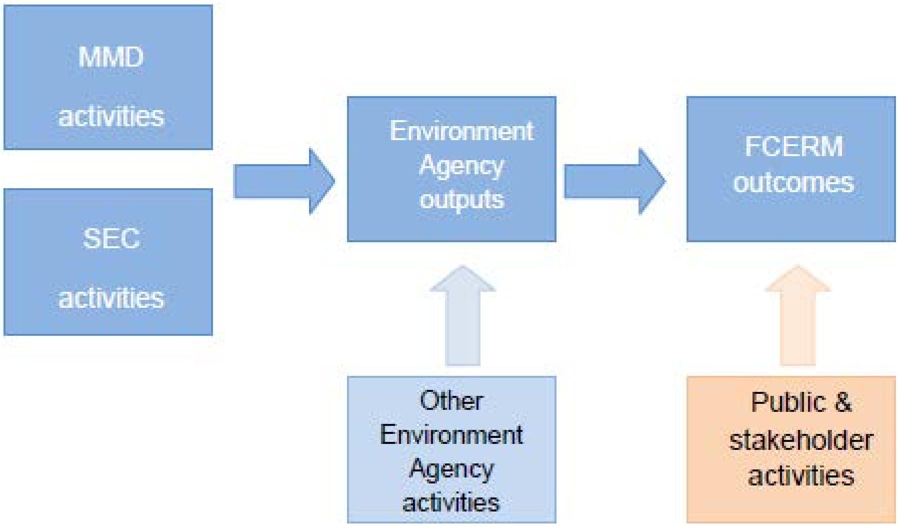


Figure 2.4 Basic structure of the system

Dependency modelling is ideally suited to tackling this type of problem. It provides a simple but mathematically robust way of understanding a complex decision environment. It can be used to integrate multiple issues, interactions and outcomes, and can reflect the mix of immediate and distant interdependent effects between MMD and SCE activities and outcomes.

In particular the participative, iterative approach to building the models leads to a depth of understanding about the nature of the system being studied which would be difficult to achieve using other methods.

The qualitative models can be understood by non-technical users and stakeholders. This is a valuable feature, particularly in the context of any natural resource management (such as FCERM) which will ideally involve interdisciplinary and participatory processes.

2.5 Choice of software

There are many software products available for dependency modelling. Seven were considered in the background research reported in the Inception Report (Environment Agency 2014). These were iDepend, DPL (Syncopation), GeNIe, AgenaRisk, Expert (HUGIN), Netica (Norsys) and BayesiaLab. Evaluation copies of the software were used to build models making use of available user support and documentation.

Five important criteria with which to inform the decision were identified following the focus group event in September 2014. Each of the seven software options was then reviewed against these criteria, based on research for this project and testing. This narrowed the choice to three priority options: iDepend, DPL and GeNIe.

2.5.1 iDepend

iDepend was of particular interest since there had been some use of this software within the Environment Agency. It is designed to be a simple drag-and-drop dependency modelling tool for non-specialist modellers. Its interface is simple, but the basic functionality is limited compared with DPL and GeNIe. (Although a new iDepend version has been developed, which provides functional resonance analysis methodology using probabilistic inputs, it is not clear whether this is relevant for this project.)

For example, to handle continuous variables (for example, cost and rainfall), iDepend requires the user to discretise the variable's domain (effectively breaking the data up into a series of single point values). This is made more difficult by limitations in the user interface when entering conditional probabilities. DPL and GeNIe have in-built methods for handling continuous variables.

iDepend's main advantage is its ability to link to live data and share live models between organisations which neither DPL nor GeNIe provide. However, it would be necessary to confirm that the iDepend hosted service cloud sharing system meets any relevant government security requirements (G-Cloud).

2.5.2 GeNIe

GeNIe is an open source, free, dependency modelling tool designed to perform all of the functions typically expected of industry-standard software. There is a wide range of analysis and reporting available and the interface is user-friendly. Although there is no commercial support, there is documentation available online (https://dslpitt.org/genie/wiki/GeNIe_Documentation).

There was no experience of using GeNIe within the project team, but research suggested it should be adequate to handle the needs of the project.

2.5.3 DPL

DPL is a user-friendly decision analysis tool from Syncopation based on Microsoft® Excel. The project team had excellent experience using DPL and knew that it had all the required functionality. The main advantages of DPL are the wide range of analyses available and flexible links with Excel. DPL is commercial software and a licence must be purchased for its use.

Based on the review and given the project's specific requirements, DPL was recommended. The main reasons for this are summarised below.

- Members of the project team had considerable experience in using DPL and were confident that it would be more than sufficient for requirements. It has a proven track record with similar problems.
- It would be possible to relatively easily transfer the final models into iDepend or GeNIe if they were able to meet the technical requirements and this was desired.

The DPL software was demonstrated at a meeting with the Environment Agency. This showed how DPL can be used to:

- construct a quantified model in a simple to use graphical interface
- run the model to calculate the probabilities of achieving the outputs

- link a dependency model to a cost–benefit model, so the model outputs a probability distribution for total net benefits
- use the model to identify the most significant nodes, for example, which nodes result in the largest change in net benefit if their states could be controlled (that is, if a probability was set to 100%)

It was agreed at the meeting to:

- use DPL to develop the MMD and SCE models
- demonstrate in the research report how it can be used to drive a cost–benefit analysis (CBA)

It would still be possible to transfer the models to another software package such as iDepend and carry out the CBA as a separate exercise.

3 Methodology

Building a dependency model involves three basic steps.

- Identify outcome measures that are most relevant.
- Identify influences that affect these outcome measures.
- Quantify the importance of cause and effect relationships by:
    - examining the number of linkages
    - expert judgement estimates of probability values expressing the strength of the relationships
    - exploring the sensitivity of outcomes to strength of each relationship

The act of building the model is as important as the final model and model outputs. The approach is therefore highly participative. The process of collaboratively building the dependency model takes participants on a journey that leads to a much better understanding of the nature of the system.

The approach adopted for this project involved working through the three steps. The first step was to carry out background research to assess and confirm that dependency modelling was a suitable approach for this project. This is reported in the Inception Report (Environment Agency 2014).

The next step was to:

- set up a focus group to establish FCERM outcome measures relevant to MMD and SCE
- develop and populate the dependency models through a series of four iterative workshops, additional meetings and webinars

Figure 3.1 shows the SCE team at the first workshop. The aims of each workshop and meeting are set out in Table 3.1. Between workshops, participants and the project team continued to develop the models; these were then brought back to the group for further evolution. After the initial planning period, the dependency modelling work was carried out over a period of five months (September 2014 to January 2015).

Figure 3.1 The SCE team at work in Workshop 1

Two models were developed for both MMD and SCE.

The first was a detailed model designed to illustrate the full range of activities conducted in each area, the processes implemented, and the internal and external factors that influence them. The purpose was to help MMD and SCE teams communicate **how** they contribute to FCERM outcomes, both internally and externally.

The second model was a compact representation of the most important influences, that is, it distilled the detailed model down to its most essential elements. This model was implemented in DPL and quantified to help explore **how much** MMD and SCE activities contribute to FCERM outcomes. A range of explorations were carried out.

The two versions of the models can be maintained as parallel 'live' documents.

Table 3.1 Participative events involved in building the dependency model

Date	Event	Objective	Participants[1]
September 2014	Focus group	• Identify and agree outcome measures	Wide range of stakeholders
October 2014	Workshop 1: Idea storming	• Identify key variables (nodes) and causal relationship structure between them (their dependencies)	Wide range of stakeholders
November 2014	Workshop 2: Refine and simplify network	• Review and refine model • Remove redundancies	Wide range of stakeholders
December 2014	Expert meeting: Review of models and software against needs	• Software demonstration • Discussion of quantification of models	Model users and developers
December 2014	Workshop 3: 1st quantification	• Agree node states, units, scales • Begin using value scales to elicit probabilities	Expert group, experienced with process
January 2015	Workshop 4: 2nd quantification	• Continue to elicit probabilities Following the workshop, the models were implemented in DPL.	Expert group
January 2015	Webinar 1	• Review the quantified SCE model	Expert group
January 2015	Webinar 2	• Review the quantified MMD model	Expert group

Notes: [1] **Participants are listed in Annex 1.**

4 Outcomes of interest

The aim of this project was to demonstrate the value of MMD and SCE activities in delivering FCERM outcomes. An early exercise therefore was to establish the overall outcomes of interest. These help to define the scope of the dependency model; only activities, outputs and influences that could, either directly or indirectly, affect these outcomes are included in the model.

The outcomes were discussed and agreed at the focus group held in September 2014. They are shown in Figure 4.1, which provides a backdrop to the development of the models. It shows how, through improving understanding and decision making, MMD and SCE activities and outputs contribute beneficially to outcomes at a high level (the blue shaded outcomes), even where this contribution is not easy to value in cost–benefit terms directly.

Every activity and output represented in the models contributes to one or more of the outcomes. But as the project progressed it became apparent that the most useful way to structure the quantified models for CBA purposes was to assign costs to the activity nodes and to assign benefits to the output nodes individually. This approach is described further in the CBA example provided in Section 6.4.

Figure 4.1 FCERM outcomes agreed for the dependency modelling

5 The qualitative models

5.1 Developing the models

The process of developing the models began in Workshop 1. This was a creative idea-storming session designed to identify MMD and SCE activities, and map them onto the outcomes.

A wide range of stakeholders from MMD, SCE and other business areas in the Environment Agency attended. Participants with specific expertise in one or other area were split into an MMD and a SCE group. Other experts were split between the two groups.

A period of individual reflection on the most important dependencies was followed by groups posting ideas about MMD and SCE activities and outputs onto a white wall. All inputs were welcomed. There were two basic ground rules.

- No suggestion is too ‘obvious’.
- No suggestion is too ‘odd’.

The groups then drew together related ideas, mapping out how their activities and other influences impacted outcomes.

The groups then presented their models to each other and areas of commonality and difference were noted and discussed. Figure 5.1 shows the SCE model at the end of Workshop 1. This level of complexity is typical of the first creative session.

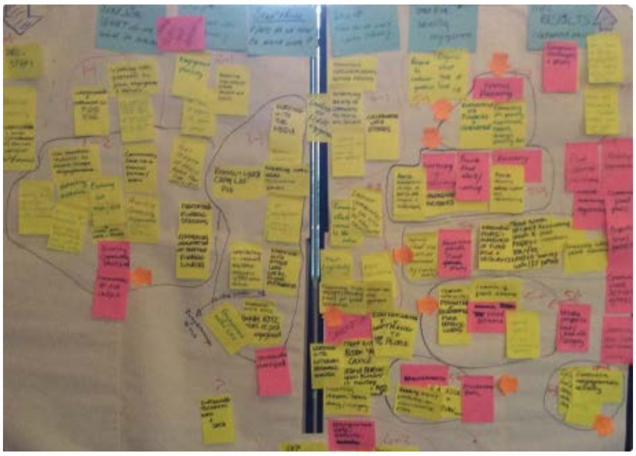


Figure 5.1 First iteration of SCE model at close of Workshop 1

Between Workshops 1 and 2, ‘clean’ PowerPoint versions of the models were created – principally removing duplication. These were circulated to participants for review and further development.

Workshop 2 further reviewed and refined the models. The focus was on clarifying the relationships on the map and then simplifying them, without losing essential detail. While there was some overlap and a clear relationship between the two models, the activities were largely independent so the models continued to be developed separately.

The evolution of the qualitative models is shown in Appendix 1 (published separately).

The models will continue to evolve. The ‘final’ models presented in this report represent a snap-shot in time. They are presented and described below.

5.2 MMD qualitative model

The MMD qualitative model is split into two parts:

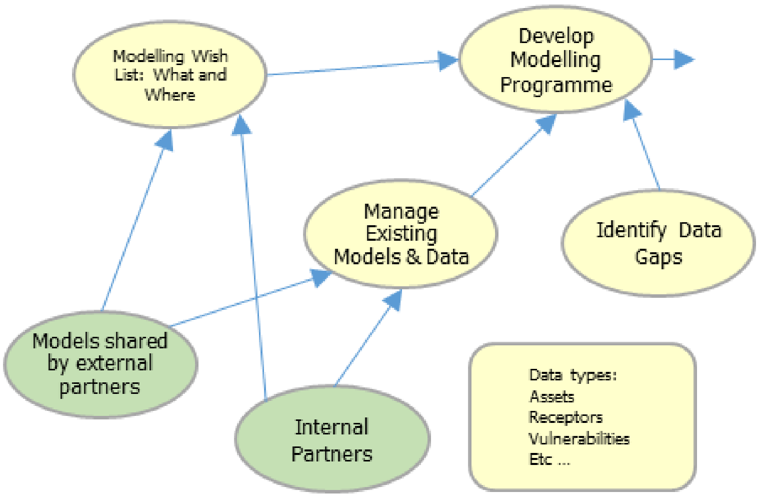
- activities leading to the production of local and national models
- uses made of local and national models

These are illustrated in Figures 5.7 and 5.8 (see the end of this section).

In the description presented below, terms in **bold** relate directly to nodes on the models. Extracts from the full maps are shown in the text for easy reference.

5.2.1 Activities leading to the production of local and national models (Figure 5.7)

Modelling priorities are captured in a needs-based **model development programme,** which is developed with internal and external partners, and includes an assessment of **data gaps**. This will identify the need for any new models.

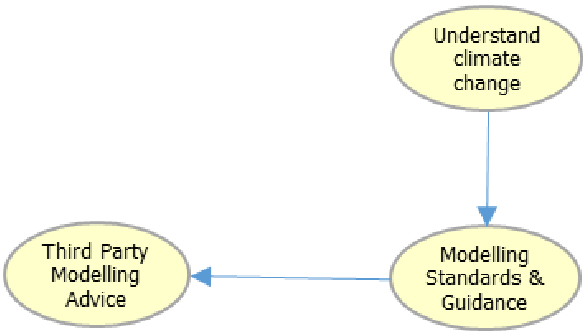


The MMD team also manages an **existing suite** of local and national models and the **data** sources that support them.

The models underpin the decisions of the rest of the business.

The models are developed at the local and national level with input from **internal** and **external partners**.

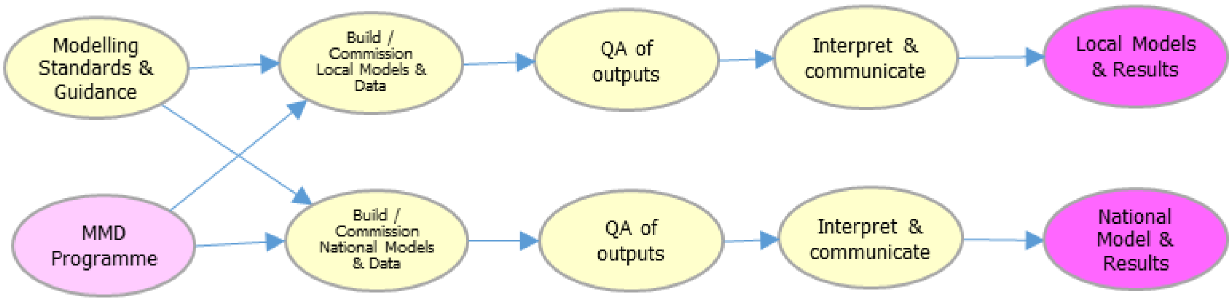
Examples of national and local models are shown in the case study in Figure 5.2.



The MMD teams are also responsible for **modelling standards** and **guidance**. These capture good practice and set different requirements for model development depending on the level of flood risk in a locality. They set the standard for the Environment Agency's own model development work (whether completed internally or commissioned).

They are also **shared with third parties**, along with data and models.

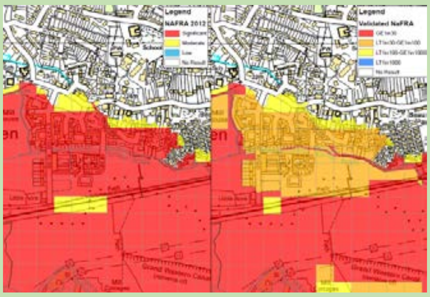
Work on **local** and **national** models is procured internally or externally in accordance with the **MMD programme**. Model output results are **quality checked** where they have been commissioned by the MMD teams before the results are **interpreted and communicated** for the benefit of the end user.



At present, local models have been developed for most high-risk locations, with national models used elsewhere. Currently models and data are managed through multiple programmes with different funding routes. Future aspirations are that:

- model and data management is consolidated under fewer better aligned programmes, with clearly defined funding streams
- the right type of model, developed to the appropriate standard depending on the risk, is available for each location
- there is a ‘single answer’ available for each location, integrated in a consistent manner to the national picture of risk
- models are maintained to meet the latest modelling standards

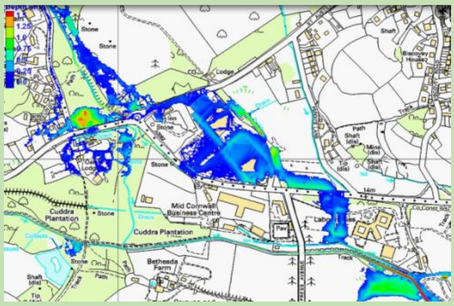
Case study: national and local models



Norton Fitzwarren National Flood Risk Assessment (NaFRA) validation

NaFRA (the National Flood Risk Assessment) provides an indication of flood risk at a national level, enabling comparison of the relative risks and their distribution within each catchment rather than a detailed, local assessment of the risk at a specific location.

NaFRA outputs are used on a daily basis to provide householders, house buyers and insurers with information about flooding risk. They are also used to raise awareness of flooding issues. Detailed local modelling can feed into NaFRA.



Par Moor flood model output

St Austell is an important town in Cornwall and has two Main Rivers flowing through it, Sandy River and White River.

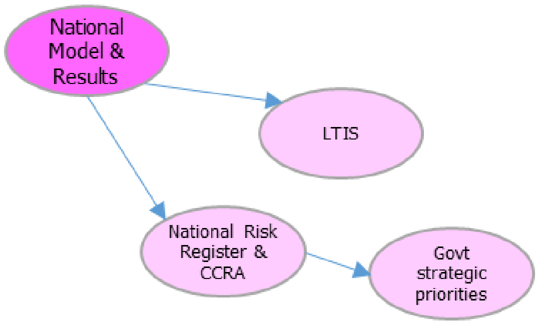
The Environment Agency and Cornwall Council worked together to provide evidence through modelling to inform strategic planning, for example, around Par Moor. This is an industrial and retail area that has experienced frequent flooding in the past three years and where significant growth areas have been identified.

Figure 5.2 Case study: examples of national and local models

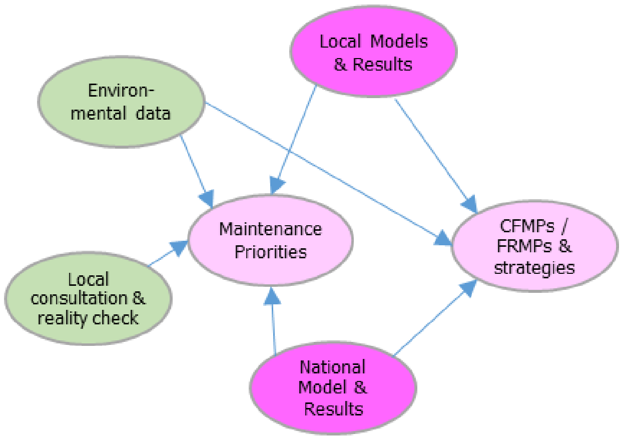
5.2.2 Uses made of local and national models (Figure 5.8)

The dependency model shows that local and national flood risk models lie at the heart of flood risk management. They are used to:

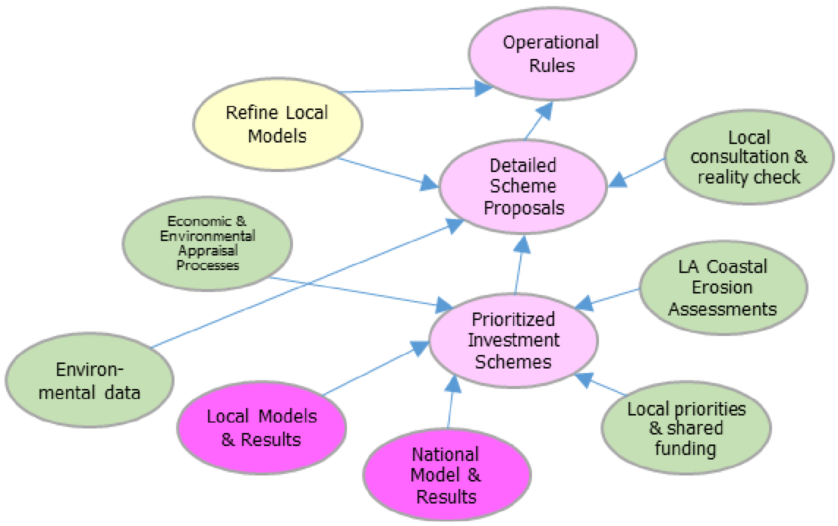
- inform **Government strategic priorities** through the National Risk Register, **Climate Change Risk Assessment (CCRA)** and **LTIS** (the Long-term Investment Scenarios Study)



- inform **Catchment Flood Management Plans (CFMP), Flood Risk Management Plans (FRMP) and Shoreline Management Plans (SMP) and strategies** (see for example the Case Study in Figure 9)
- provide evidence to help set **maintenance** priorities, and



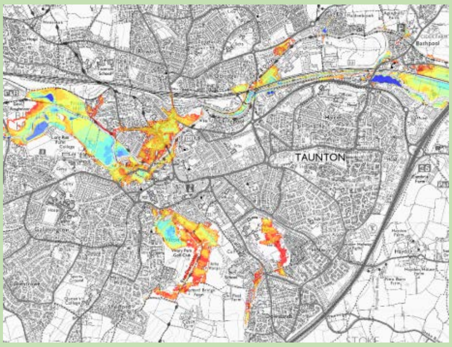
- set **investment priorities** and help develop **detailed scheme proposals** and **operational rules** (see for example the Case Study in Figure 10).



Case study: strategic planning

Taunton is one of the major areas for new development within Devon.

The MMD team have developed and refined a detailed model of the River Tone and its tributaries over the past few years. This model is regularly licensed to private developers to underpin their Flood Risk Assessments (FRAs).



The model is helping deliver an important component of Taunton's strategic plan for its new developments, which total tens of thousands of houses, through appraisal of options to mitigate flood risk.

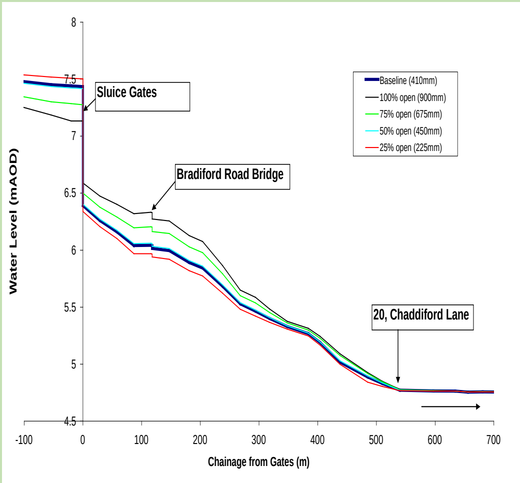
Developer FRAs generally address very local risks and can provide important updates of the flood risk information on a watercourse or catchment. Detail from these has therefore been incorporated into Environment Agency models to improve detail.

Figure 5.3 Case study: use of models to support strategic planning

Case study: operational rules

A sluice gate used to control water levels in Bradiford Water in Devon was set at a restrictive level due to uncertainty in how gate settings would affect river levels and the risk of flooding downstream.

Modelling was used to find the setting that would maximise the downstream level without causing property flooding. This brings benefits for the ecology of the river and improves its amenity value. It also reduced the potential for blockage at the gate because of the wider setting.

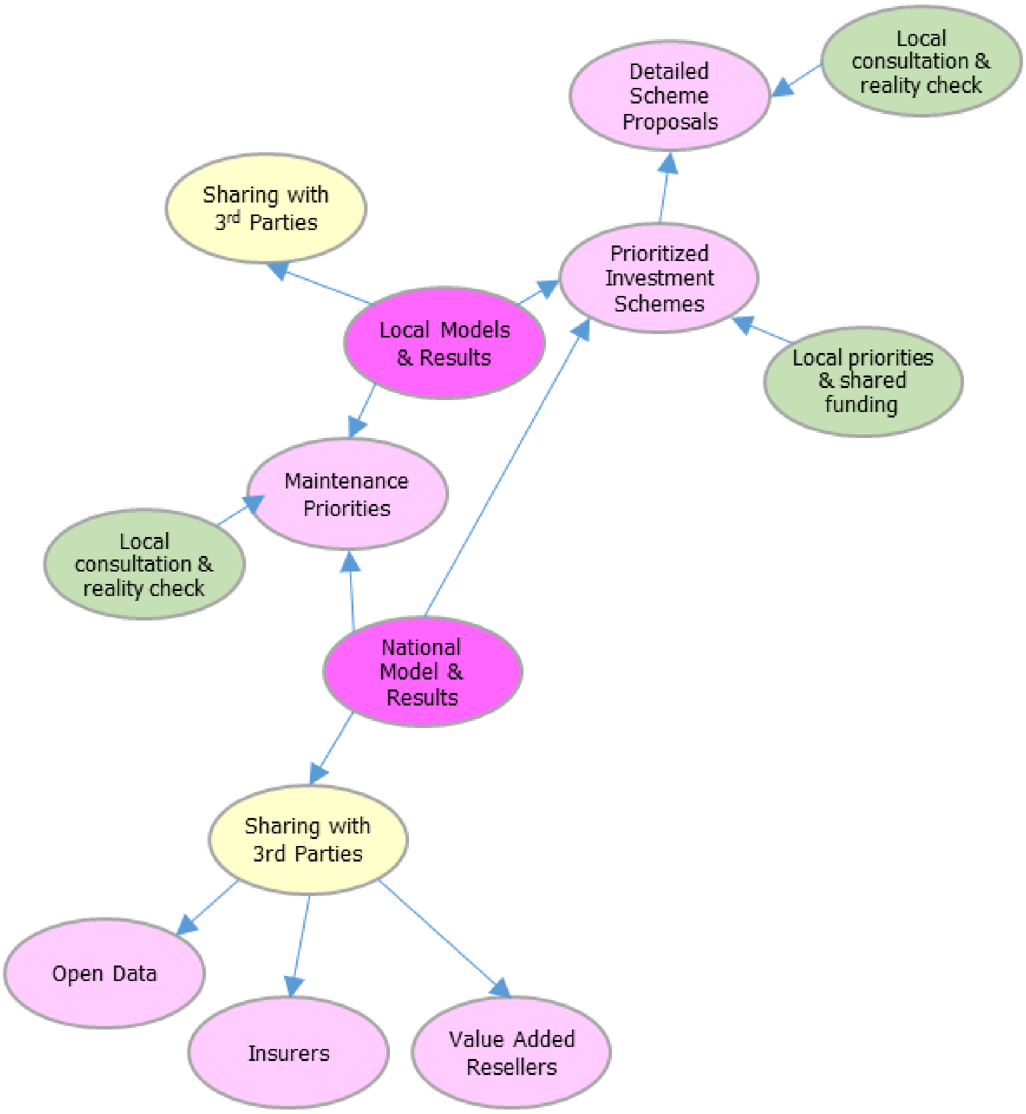


Water level profile along Bradiford Water for a 1 in 20 year event with different gate openings

Figure 5.4 Case study: use of models to optimise operational rules

Models and outputs are also shared outside the Environment Agency, for example, with insurers and developers. This not only helps improve local flood risk management decision making, but by feeding back more detailed information on local watercourses it can improve the quality of the Environment Agency's local models and help ensure they are up-to-date.

The case study in Figure 5.3 provides a good example of this. **Local consultation** (SCE), expert input and **reality checks** also help improve the quality of the models and maps.



During discussions, the MMD group raised a number of areas where they felt improvements could be made.

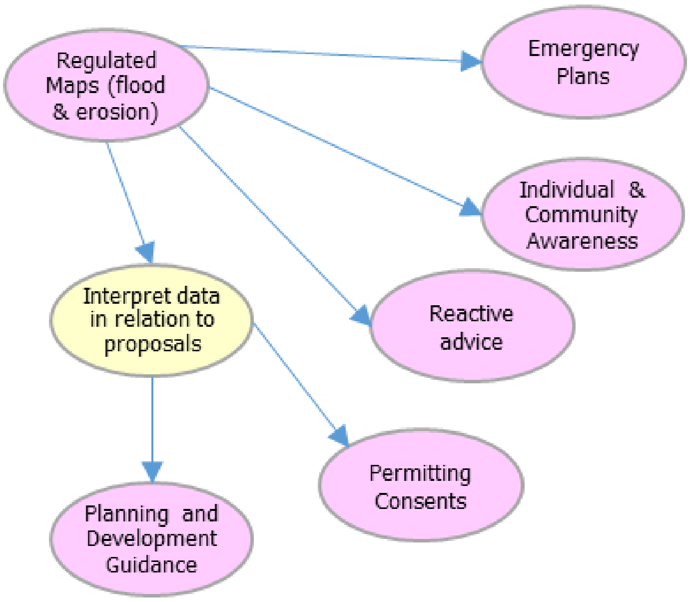
- Local models are not currently available for all high risk areas. While local consultations and reality checks are important, some local decision making may rely too much on national models.
- Improved model quality would lead to better investment decisions, particularly with respect to FCERM scheme location and design.

Helping reduce flood risk

Local and national models help individuals, communities and local government manage flood risk by:

- providing input to **planning and development guidance**

- providing input to the design of **emergency plans** (see the case study in Figure 5.5)
- informing individual and community **awareness campaigns** and activities – Figure 5.5 shows an example of how models can be used to understand risks in a locality better, and then by producing visualisations, help communicate them more effectively



- informing decisions on **permits** – flood defence consents are needed before people can undertake certain activities in, on, over, under or near watercourses to ensure they do not increase flood risk; modelling helps determine whether activities will increase flood risk
- providing **reactive advice** on request to government and other users of the published flood maps

Many of these outputs are delivered through the National Flood Risk Assessment (NaFRA) and other **regulated maps** which are required under EU legislation (for example, the Surface Water Flood Risk map and the Risk of Flooding from Reservoirs map.

Case study: emergency planning

Communities along the River Chew in Somerset have suffered numerous severe flood events over several decades, the most recent in 2012 with over 40 properties flooded and one fatality.

Updates to the local model will help test various scenarios put forward by community action groups. The modelling will help with emergency planning by providing detail on hazard and flow routes through the communities.

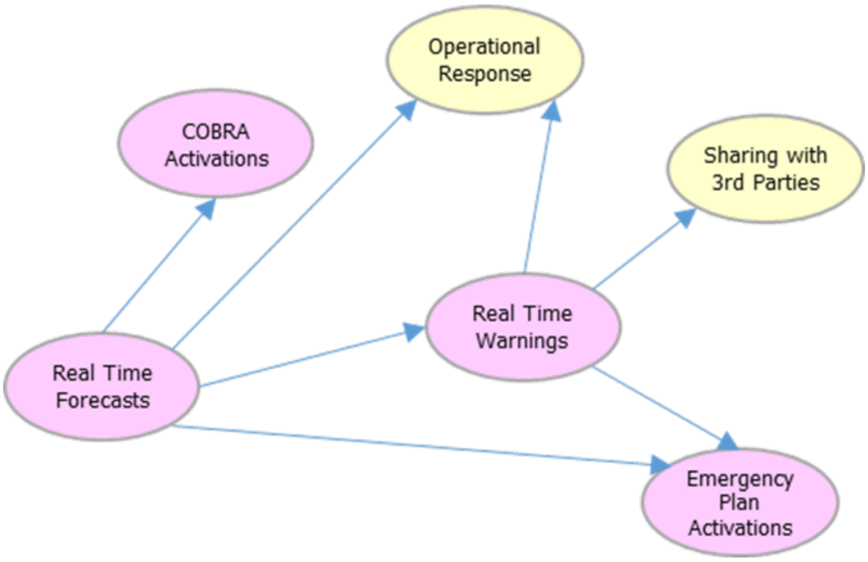
The model outputs will be used to create visualisations to communicate the flood mechanisms and to help the community further develop their flood action plans using the lead time data and hazard from the modelling.

Figure 5.5 Case study: use of models to support emergency planning

Informing the response to flooding events in real time

Flood risk models provide real time forecasts for when thresholds will be breached in flood warning areas (FWAs). They are therefore a crucial input to the flood warning system which helps individuals, communities, and local and national government respond to flooding events. They also trigger:

- **operational responses**, for example, mobilising Environment Agency staff to high risk locations
- COBRA and/or more local **emergency plan activation**



Early warning of floods enables individuals and communities to take measures to reduce the impact of flooding. It also enables government to mobilise help more effectively and in advance of the flood occurring (see the case study in Figure 5.6).

Case study: Floodline Warnings Direct

Opened up to the public at the beginning of 2006, Floodline Warnings Direct (FWD) is a free service to alert the emergency services and local residents to the risk of imminent flood. It has seen heavy usage. For example, during the summer of 2007 when over 47,000 homes and 8,000 businesses were flooded, FWD issued 220,000 warning messages to the public in June and July 2007.

By continually analysing Met Office forecasts, rainfall radar, ground saturation levels and river sensor telemetry, together with detailed maps of possible flood areas, the Environment Agency decides when to issue flood warnings.

Properties at risk in the expected flood area can be quickly identified using their precise geo-coordinates and alerts issued using their communication preferences stored in the customer database – landline or mobile phones, email, fax, SMS text, pager or letter.

Figure 5.6 Case study: use of models to inform flood warnings

Floodline Warnings Direct is not yet delivered uniformly across communities at risk. Both the MMD and SCE groups identified areas where MMD and SCE activities could help improve the flood warning service through, for example:

- better management of data, with clear ownership and accountability
- coordination of programmes (modelling, forecasting, flood warning) across FCERM and the wider business
- a more consistent approach to river level information online, and communication and guidance

- developing a system of gradually escalating thresholds rather than the current fixed thresholds and improving lead times
- getting local community groups more involved in shaping models, flood warnings and forecast requirements (community based flood warnings), community owned and maintained telemetry systems and alarms
- awareness raising to improve uptake of the service
- getting better information on the quality and performance of forecasts and consistent flood data recording and collection (validation of flood warnings)

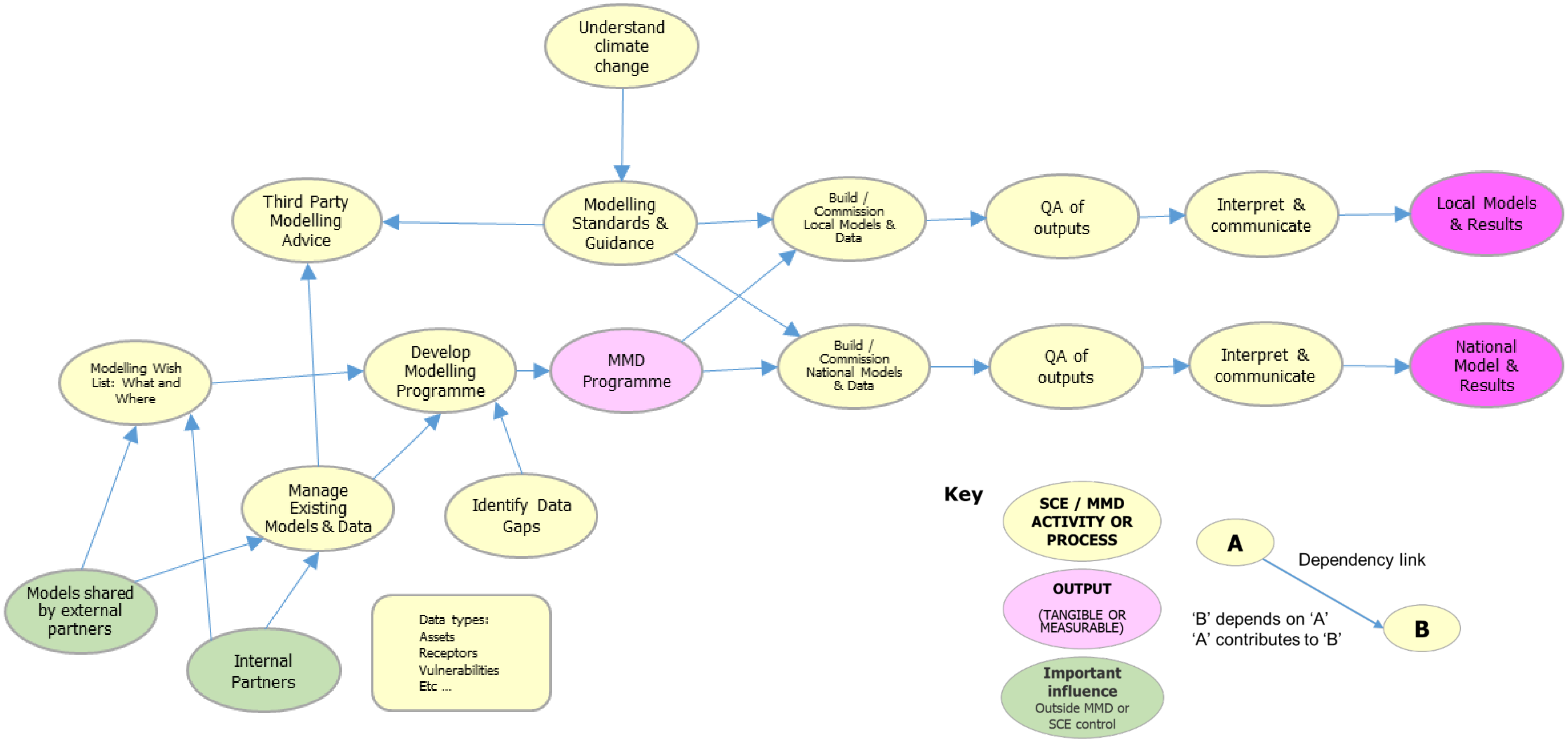


Figure 5.7 MMD qualitative model Part 1: activities leading to the production of local and national models

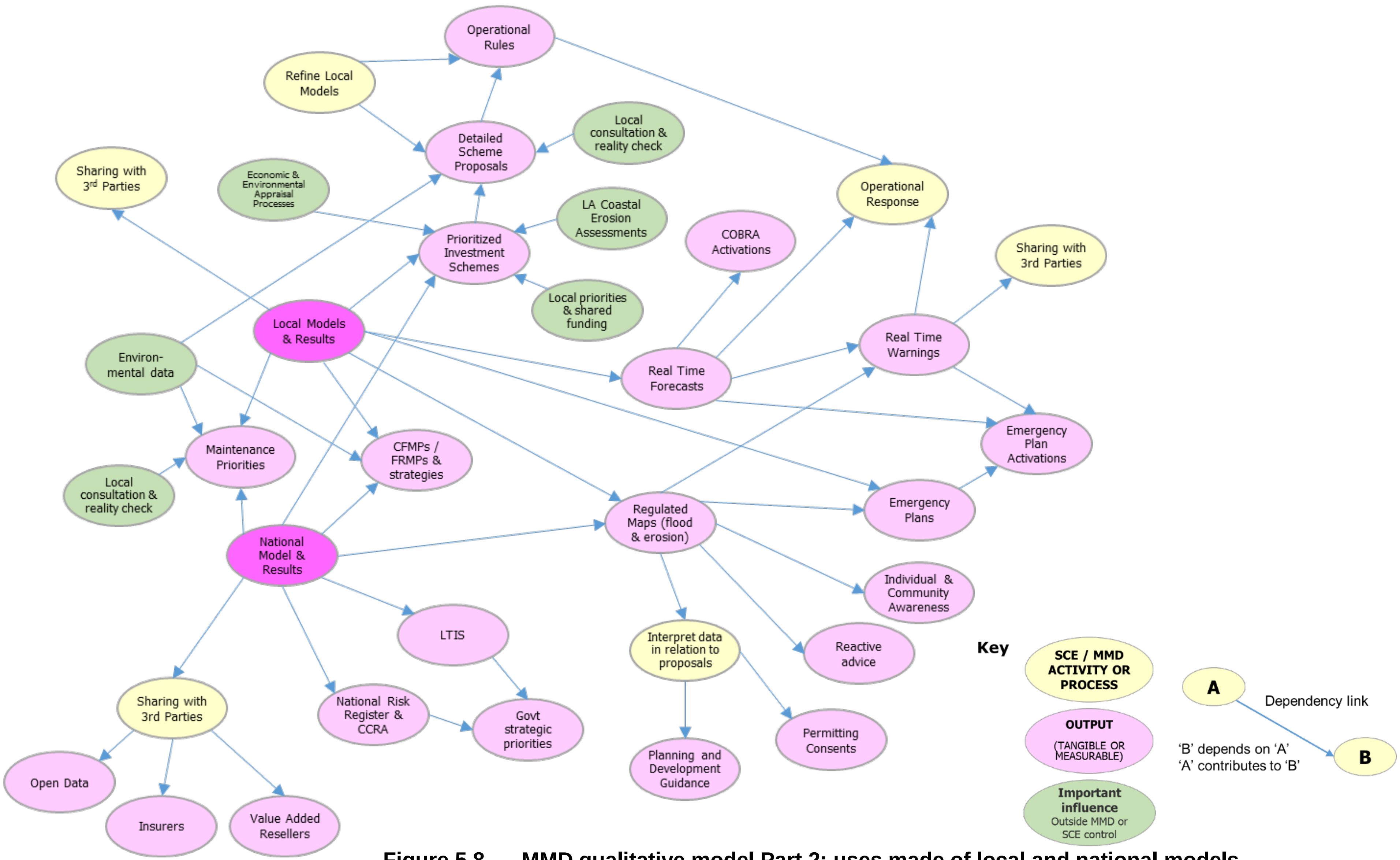


Figure 5.8 MMD qualitative model Part 2: uses made of local and national models

5.3 SCE qualitative model

The SCE qualitative model (see Figure 5.12 at the end of Section 5.3) illustrates the wide range of activities performed directly by staff carrying out FCERM engagement activities. The model shows, in a simplified form, the processes by which they are put in place.

In the description presented below, terms in **bold** relate directly to nodes on the models. Extracts from the full map are shown in the text for ease of reference.

Area **strategic engagement plans** are developed, which in turn inform **specific community engagement planning.** The plans are informed by a range of inputs:

- General socioeconomic environment – Political, Economic, Social, Technological, Legal and Environmental influences (**PESTLE**) and local **situational analysis** using the Environment Agency's **Working with Others (WWO)** methodology (situational analysis is about understanding the context of the local engagement)
- **Strategies and plans** (for example, flood risk management plans)
- Outputs of modelling and analysis to **identify and prioritise flood risks** (there is a clear link to MMD activities here) such as the Communities at Risk Project
- Responses to past **flood incidents** in the area/community
- **Evidence gathering** through market research, and evaluation of previous engagement activities
- Input from external partners

The model shows the SCE activities feeding in to bring about tangible benefits across FCERM activities, outputs and outcomes, including:

- development and delivery of plans and programmes such as:
  - statutory and local strategies and plans
  - FCERM capital schemes
  - maintenance plans
- flood resilience
- flood response and recovery

- responding to enquiries

Strategic engagement plans at an area level are not yet in place in all areas. However, following the implementation of the Local Measures Framework, clear engagement objectives and evaluation measures are described and reported for at least three priority communities in each area. Engagement and communication plans have also been developed for major projects such as the delivery of schemes.

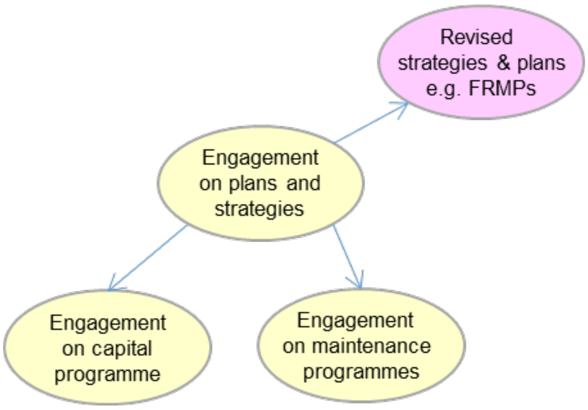
An underlying issue is that FCERM engagement is realised through a number of teams including those in the FCERM function, those with Incident Management roles as well as through other parts of the Environment Agency. As such, reporting and leadership is split within the business. The Environment Agency is continuing to address the challenge of how to improve strategic links for engagement.

Evaluation of SCE activities and outcomes is an important activity; results need to be continually fed back to improve process but also to demonstrate the benefits of SCE.

Development and delivery of programmes and plans

Strategies and plans

SCE supports the development of **statutory plans** such as FRMPs and SMPs and **local strategies and plans** by ensuring that internal and external stakeholders are able to share their views and influence their development. The aspiration is to:



- encourage early, open and transparent engagement in a location
- raise awareness of flood risk issues
- identify suitable options to reduce the risk of flooding

This engagement forms a good spring board for more specific conversations around FCERM **capital schemes** (see the case study in Figure 5.9), **maintenance** and resilience planning in communities at risk.

SCE helps inform the development of the six-year FCERM **capital investment programme** as well as shaping the design and delivery of these schemes. Engagement around the design and delivery of local schemes allows local needs and aspirations to be considered where there is scope to influence specific aspects of these schemes. It also helps boost local understanding, address concerns and ultimately gain support for the scheme. Through engagement, staff can also explain the need for, and secure, partnership funding (direct or in-kind) contributions.

Engagement can be achieved with the help of local partners.

Case study: FCERM capital schemes

The Morpeth Flood Scheme is a £27 million partnership project between the Environment Agency and Northumberland County Council. It will reduce the risk of flooding to over 1,000 homes and businesses in this historic market town.

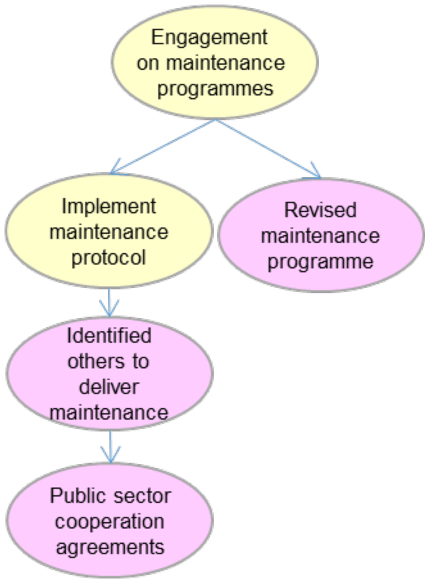
The Environment Agency has engaged extensively with the local community and stakeholders since planning began. This became particularly important after September 2008 when the town suffered significant flooding.

Lots of interest and positive comment were generated about the bespoke information centre which was set up. Targeted communications and engagement helped improve the implementation of the scheme and enabled the Environment Agency to sensitively handle some difficult issues, such as when building a flood wall through 29 private gardens.

Figure 5.9 Case study: use of SCE to improve a capital scheme

Maintenance planning

The Environment Agency uses a risk-based approach to assess the need and justification for maintenance work and invest in those activities that will contribute most to reducing flood risk per pound of funding.



Maintenance activities include:

- operation – inspecting and operating assets
- conveyance – improving the flow of water in a channel
- structures – maintaining structures and defences
- Mechanical, Electrical, Instrumentation, Control and Automation (MEICA) – carrying out minor repairs and replacements to pumps and tidal barriers

Engagement on maintenance could be about the **maintenance programme** or about implementing the **maintenance protocol**. Outputs could be a **revised maintenance programme** or **Public Sector Cooperation Agreements**.

Engagement with communities can help explain the maintenance 'story' as well as inform the programme. It can help explain why certain activities are being carried out, while others are not, or indeed, why a long-running maintenance activity is not being continued. The annual FCERM maintenance programme can be downloaded from GOV.UK (https://www.gov.uk/government/publications/river-and-coastal-maintenance-programme).

Local teams work with other Risk Management Authorities such as Internal Drainage Boards (IDBs) to identify any opportunities to coordinate maintenance work, seek efficiencies and reduce costs. Public Sector Cooperation Agreements allow others (for example, IDBs), to undertake maintenance works on a Main River where there is benefit to both parties and to local communities.

Engagement before a flood

Engagement before a flood helps communities build resilience (see the case study in Figure 5.10). It helps reduce the extent and degree of flood damage by increasing awareness of flood risks and helping people prepare in advance. It facilitates development of community flood plans, encourages take up of the flood warning service and property level protection products, and establishes flood action groups and flood warden schemes. Together these measures help ensure communities know when to respond and are prepared to take action.

The Environment Agency is not the only flood risk management authority and not the only organisation doing work on community preparedness. Therefore it can be difficult for the Environment Agency to track and provide a coherent picture of community preparedness. There is an aspiration that the Environment Agency will work with other risk management authorities to consider how they can measure a community's 'flood readiness'.

Case Study: building resilience

The Environment Agency has been working with Sheffield City Council and the River Stewardship Company to support an effective flood warden network. It has co-sponsored a flood wardens' seminar, attended warden group meetings, and sought formal and informal feedback from the wardens themselves. It has also provided advice, materials and financial support to various initiatives. There is now a strong, capable flood warden network in place, which continues to seek ways to improve what they do and how they do it. They have provided effective support in the event of floods, helped raise flood awareness in their communities and have made good progress in developing their community flood plans.

The Environment Agency supports the Community Riverlution Network. This is a River Friends Network designed to share ideas and resources to make rivers and waterways the best they can be across Sheffield. Groups such as the warden group can also use the Network to help raise awareness of flooding and highlight how they are working to make their local community more resilient.

The Riverlution project used the concept of stewardship and volunteer days to engage with the community around flood risk. A large part of the work focused around the Sheffield Flood Warden network giving them the skills and confidence to run their own volunteer days and making space for their plans on the Riverlution website.

Riverlution
River Friends Network

Figure 5.10 Case study: use of SCE to build resilience

The SCE group's experience is that engaging communities before a flood brings additional benefits in the event of a flood. It finds that communities that have already been engaged are much more willing and able to engage constructively around the issues in the recovery stage.

Aspirations for community engagement

The SCE group's aspirations for delivering more effective community engagement include more consistently:

- taking a more proactive approach
- joining up its engagement around all FECRM issues with a specific community
- strategically planning an integrated approach with partners such as Local Resilience Forums, risk management authorities, voluntary sector and others

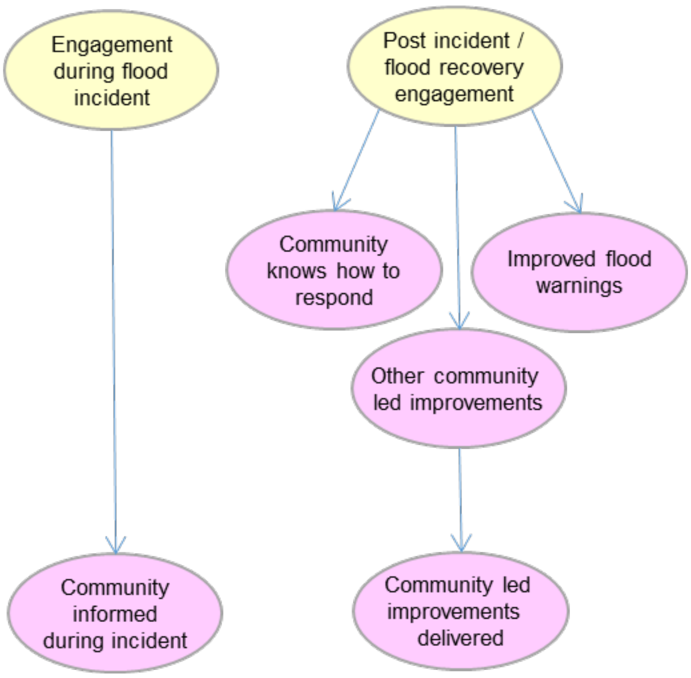
Flood response and recovery

Engagement during and immediately after a flood helps flooded communities in a number of ways. It can provide information about the developing incident, give help and advice on how to minimise damage and speed recovery, and answer questions. It provides the opportunity to:

- ensure a more effective, informed response
- learn what changes are needed to improve future response and recovery
- build ownership of flood risk among individuals and the community

Environment Agency Flood Ambassadors provide on the spot advice **during an incident** and are an important link for communication and action between communities and the response team.

Flood Ambassadors are identified within the Major Incident Recovery Plan as a potential role to support community engagement. Experience suggests that, unless the flood ambassadors have some local knowledge of the area or can offer practical help, it can be a difficult role to fulfil.



Engagement after a flood involves supporting other risk management authorities to help individuals and communities recover from flooding (see the case study in Figure 5.11). It also provides an opportunity to collect data to inform FCERM improvements, including improvements to the **flood warning system** (see Section 5.2.2). This can reduce the impact of future flooding. Engagement in the period following a flood feeds back into the activities discussed above around community planning and engagement before a possible subsequent flood.[2]

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[2] In the simplified modelling used for quantification, the pre-flood and post-flood elements are combined into a single part of the model, separate from the 'during flood' element.

Case Study: engagement following a flood

In December 2013 the communities of Brancaster, Salthouse and Cley in Norfolk were badly flooded by a tidal surge.

Community engagement following the flood focused on understanding what is important to the communities and finding solutions that would meet local needs. Working with its partners, the Environment Agency quickly organised a drop-in surgery for the community and local businesses reaching over 200 people.

The Cley Norfolk Wildfowl Trust under water following the surge tide

© Brian Egan

The overwhelming immediate community need was to make footpaths safe before the holiday season began in earnest (April 2014). The Environment Agency was able to achieve this with support from partners. Communication with the local partners continues with further improvement and remedial works being carried out on-site as the ground conditions improve.

Figure 5.11 Case study: engagement following a flood

Community led improvements include:

- development of community led flood action plans
- communities fundraising for schemes to supplement FCERM Grant-in-Aid funding (for example, crowdfunding or charity funding)
- setting up a flood action group which is recognised as the point of contact, communication and expertise for flood issues in the locality
- involvement of the flood action group in strategic flood risk governance (for example, coastal groups or local flood risk management boards)

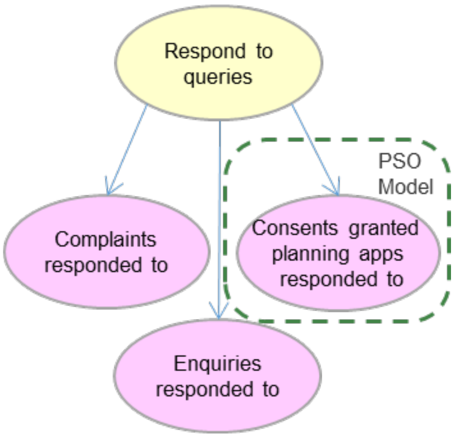
The SCE group felt that, as communities take greater ownership for their risk, the Environment Agency's engagement should seek to facilitate:

- better access to good practice guides, templates and practical information (for example, to support communities to prepare their flood action plans)
- provision of information and support at a community level
- flood action group representation on Regional Flood and Coastal Committees and Local Flood Risk Management Boards and better engagement by these forums and parish councils/ward councillors with the flood action groups

Responding to enquiries

Another aspect of the Environment Agency's engagement is **responding to complaints and enquiries** (including from MPs and communities). The Environment Agency is required to respond in timescales set out in service level agreements.

The SCE group recognises that good engagement and communication helps improve community understanding of FCERM issues and in turn this often reduces the number of enquiries



and complaints received.

Advice on consents and planning applications is covered in more detail in a map being developed for Partnership & Strategic Overview (PSO) teams as part of a separate project.

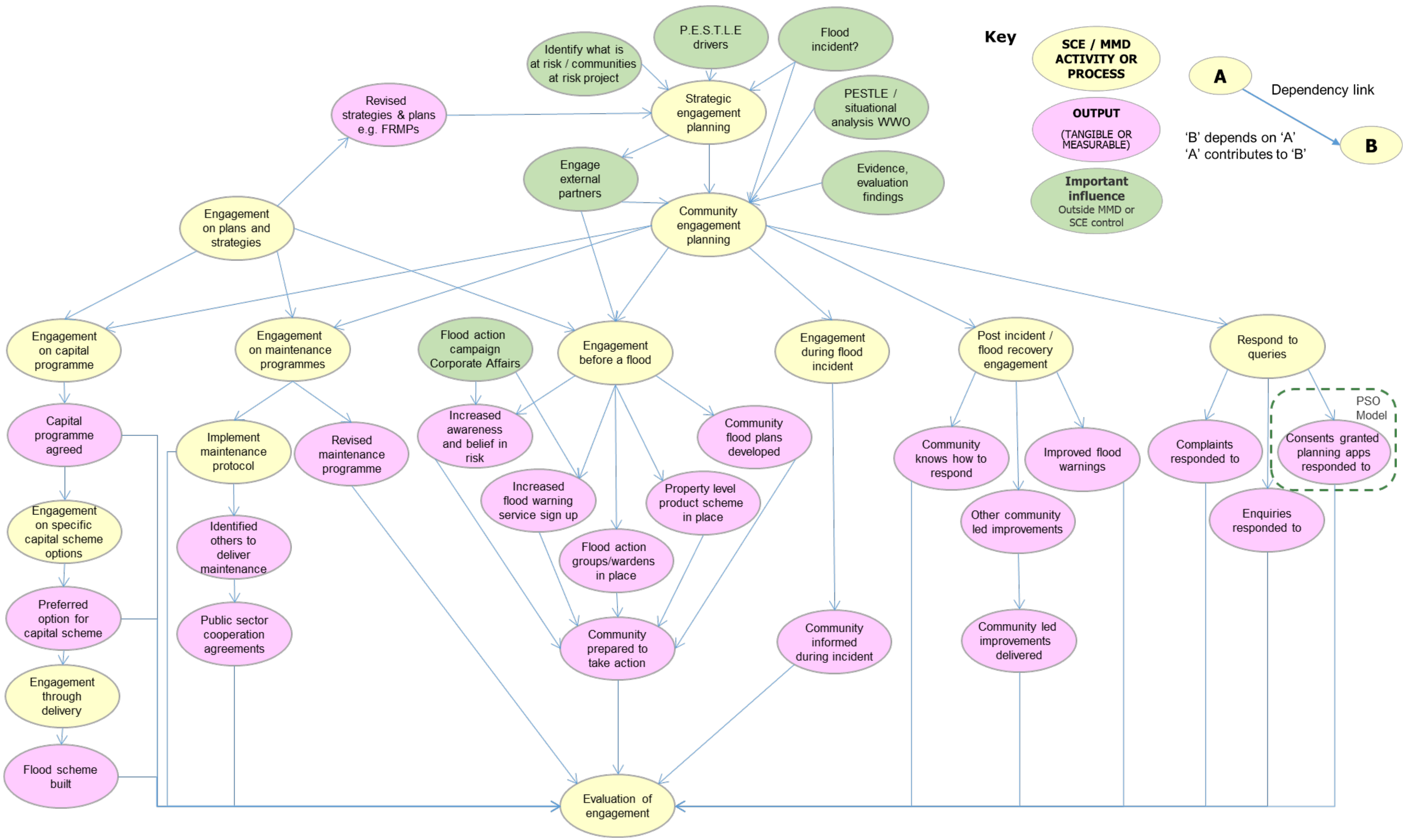


Figure 5.12 SCE qualitative model

6 The quantitative models

6.1 Developing the models

The quantitative models were developed in Workshops 3 and 4 and the quantification presented during two webinars. Development of the qualitative models continued in parallel to reflect further insights gained during the quantification discussions. The process involved:

- simplification of the models
- review of the qualitative and simplified models
- quantification of the model

6.1.1 Simplifying the models

Workshop 3 started the process of quantifying the models, but before doing this, the models were simplified to aid quantification.

The MMD and SCE models have different structures, but both include critical activities that contribute to a set of common outputs. These outputs then contribute to the higher level outcomes presented in Section 3. The models were simplified by focusing at the level of the common, tangible outputs such as flood warnings and emergency plans.

Chains of activities were combined where these were linear chains only and primary outputs were listed. This helps reduce model run times, as every node removed reduces the total number of pathways through the model by a factor of two. It does not affect model outputs and the detailed structure remains visible in the qualitative maps.

6.1.2 Review of the qualitative and quantitative maps

The review processes resulted in some changes to the maps. The evolution of the maps through this process is shown in Appendix 1.

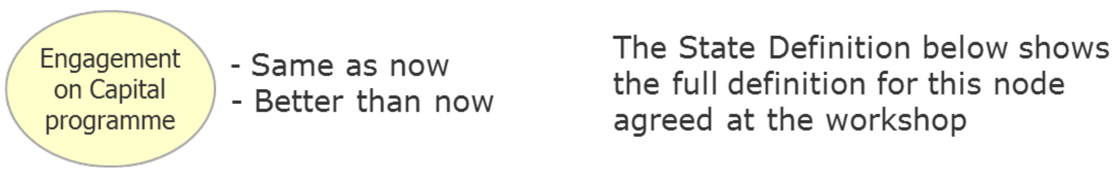
6.1.3 Quantifying the model

There are two steps required to quantify the model:

1. Definition of states for each node
2. Estimation of probabilities

Step 1: Node state definitions

The first step in quantifying a model is to define each node in terms of its possible states. For example the node: ‘Engagement on capital programme’ could have two states:



Participants were asked to focus on the status quo now and how a change to the status quo would produce increased benefit. This framing makes the model show the opportunities from SCE and MMD activities. For example, Figure 6.1 shows state definitions for the outputs that would be improved by improving engagement on the capital programme.

Activity C: Capital programme	
As now	**Better**
▪ Consultation throughout process ▪ Community involved on individual schemes (via option selection and Regional Flood and Coastal Committees) ▪ Uncertainty as to how consistently engagement follows the WWO methodology (the Environment Agency's framework for stakeholder engagement, especially where this is delivered through suppliers) ▪ Spatial mapping of FCERM six-year capital investment programme supports engagement (Google maps used to communicate six-year investment programme in 2014)	▪ When contracted out (by the National Capital Programme Management Service), engagement delivery quality maintained ▪ Engagement as part of criteria at Project Appraisal Board – right engagement resource committed to project ▪ More consistency in approach to same engagement activity to reduce duplication of effort and more consistently apply good practice (for example, have one good practice guide to running drop-in surgeries, which all Environment Agency areas adhere to) ▪ Seek to have joined up conversations with the community about all FCERM issues ▪ More transparency in how the Capital Programme is developed

Figure 6.1 Example of state definition

An alternative would be to frame it in terms of risks, for example, what outcomes would be made worse by reducing the Environment Agency's engagement on the Capital Programme. In this framing the two node states would be:

- Same as now
- Worse than now

Following Workshop 3, the project team issued further guidance to help Environment Agency staff continue to develop these state definitions remotely.

Workshop 4 was used to review progress, complete the process of assigning state definitions and to carry out Step 2 (probability estimation).

Step 2: Probability estimation

The second step in quantifying the model was to assign probabilities that express the strength of dependence between each linked node. Participants were asked to mark each arrow as a strong or a weak dependence before being asked to assign probabilities as follows:

1. **A depends on B and nothing else**
   Implies if B is 'improved', there is a high chance that A is 'improved', for example, 95% probability.

2. **A depends on B and some other factors** (that is, not MMD or SCE activities) If B is ‘improved’, there is a chance that A is ‘improved’, for example, 75% probability.

3. **A depends on B and C** All combinations need to be considered.

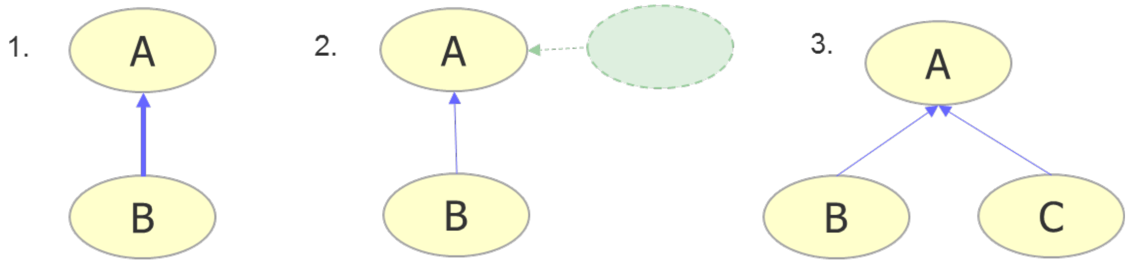


Figure 6.2 shows an example of how probabilities are determined. This is done on the basis of expert judgement by the group, after a discussion of the factors affecting the strength of each dependency.

Following Workshop 4, the final maps and the probability judgements were entered into DPL models for SCE and MMD respectively. A webinar was then conducted with each group to share the emerging results.

Establishing probabilities – independent node

Node: engagement on capital programme

The left hand node is independent of any other nodes because it has no arrows entering it. So the question asked is 'what is the chance that the engagement on the capital programme will be the same as it is now or better than it is now, based on current plans and budgets?' This requires a timeframe to be specified, usually something quite short, for example, within the next year. The examples below show how the question could be answered in different circumstances.

Example 1: I am very confident that the engagement on the capital programme will be better than it is now (see Figure 6.1 for the definition of 'better') within one year.

Node: Engagement on capital programme	Probability: must sum to 100%
Same as now	Very Low, for example, 5%
Better than now	Very High, for example, 95%

Example 2: I don't know if engagement on the capital programme will be better than it is now within one year.

Node: Engagement on capital programme	Probability: must sum to 100%
Same as now	Unsure, 50%
Better than now	Unsure, 50%

Establishing probabilities – dependent node

Node: Develop and implement capital programme

The middle node is connected to the left hand node by an arrow, so we need to specify some conditional probabilities. The question we are now asking is 'what is the chance that the capital programme will be the same or better than now **if** the engagement is the same or better than now'. We need to fill in a small table of numbers for each possible permutation, for example:

Conditioning node: Engagement on capital programme	Dependent node: Develop and implement capital programme	Conditional probability (must sum to 100%)
Permutation 1		
Same	Same	High, for example, 75%
	Better	Low, for example, 25%
Permutation 2		
Better	Same	Low, for example, 25%
	Better	High, for example, 75%

In this example, there is quite a strong relationship between the quality of the engagement and the quality of the capital programme. However, there are some other factors at work as well because there is a 25% chance that the capital programme would improve anyway even if the quality of the engagement was not changed.

Figure 6.5Establishing probabilities

6.2 MMD quantitative model

6.2.1 Simplified MMD model

By the end of Workshops 3 and 4, there was a good understanding of how the full qualitative dependency model could be simplified to a point where just the essential elements remained so as to demonstrate the additional value that comes from making a quantified model. Figure 6.3 shows the final simplified MMD model.

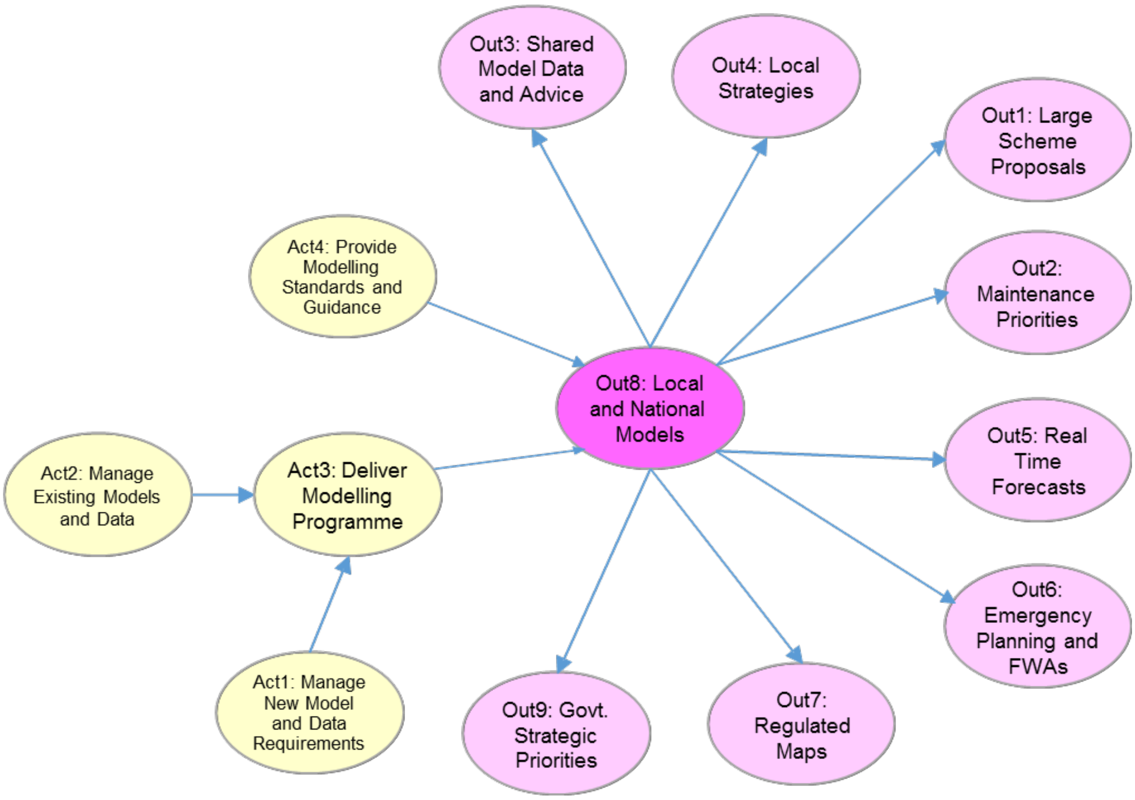


Figure 6.3 Final simplified MMD model used for quantification

In this representation, there are four key MMD activities (labelled Act1 to Act4) which contribute to the production of a suite of local and national flood risk models. These flood risk models are the primary output from the modelling programme and they feed in to a number of other major Environment Agency outputs.

The strength of the dependencies represented by the arrows determines how making improvements to MMD activities would improve the primary output (the local and national models) and hence improve the wider Environment Agency outputs.

Figure 6.4 is a screen shot from DPL, showing how the simplified MMD model is constructed using the graphical user interface to exactly match Figure 6.3.

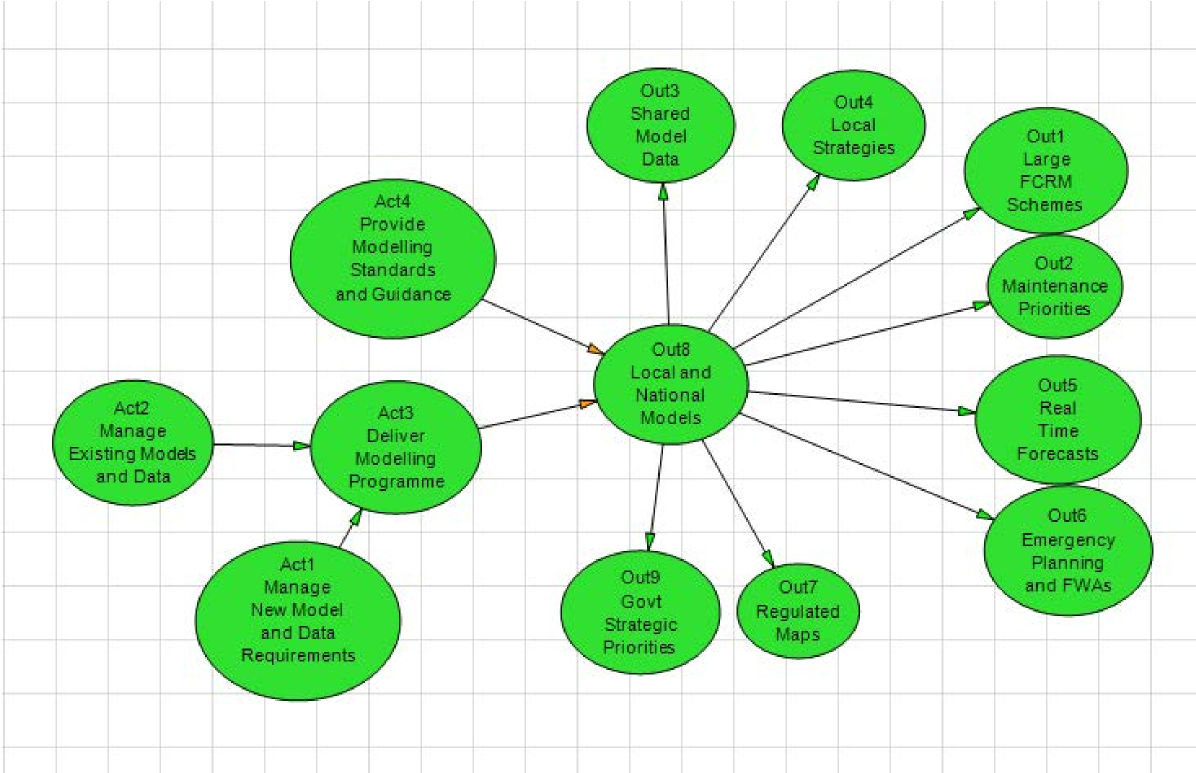


Figure 6.4 Simplified MMD model constructed in DPL

As discussed in Section 6.1.3, each node in the model has two states representing 'same as now' and 'better than now'. The full state definitions for the MMD model can be found in Appendix 2 (available on request by emailing fcerm.evidence@environment-agency.gov.uk).

A representative probability scale was used to define the strength of the dependencies, shown in Table 6.1. Each dependency was categorised from 'Very High' to 'Very Low' and the corresponding probability values entered into the DPL model (in some cases after adjustment up or down). The values used in the model can be found in Appendix 3 (available on request by emailing fcerm.evidence@environment-agency.gov.uk).

Table 6.1 Representative probability scale for the MMD model

Scale	Probability range	Probability used in model
Very High	90–100%	95%
High	60–90%	75%
Equal (or Unknown)	40–60%	50%
Low	10–40%	25%
Very Low	0–10%	5%

6.2.2 MMD model results

The DPL software analyses the combined effect of all the dependencies that have been specified to calculate the overall probability that each node is in its 'same as now' or 'better than now' state. The results for the output nodes are shown in Figure 6.5.

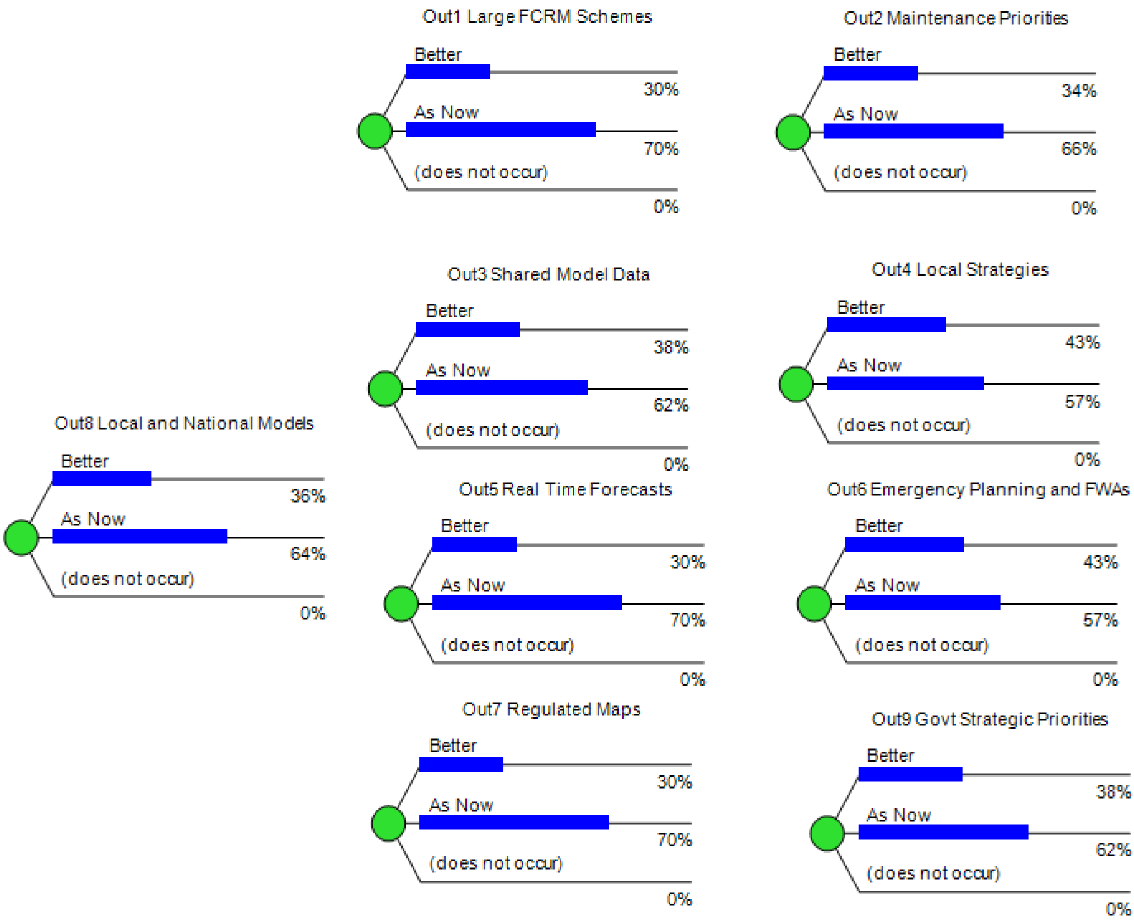


Figure 6.5 Overall probability values for the Local and National Models outcome node and the eight Environment Agency outputs that depend on it

Figure 6.5 shows that there is currently a low chance that the Local and National Models node (Out8) will achieve its ‘better than now’ state without further intervention.[3] The eight Environment Agency outputs that depend on this node therefore all show relatively low probabilities for achieving ‘better than now’ as well.

Considering the eight Environment Agency outputs together, DPL can also calculate a probability distribution for how many of them achieve ‘better than now’, as shown in Figure 6.6.

[3] The actual calculated probability shown in the figure is 36%, but it is important to remember that the input data were only specified using a representative probability scale. A value of 36% falls in the Low range of 10–40% on this scale.

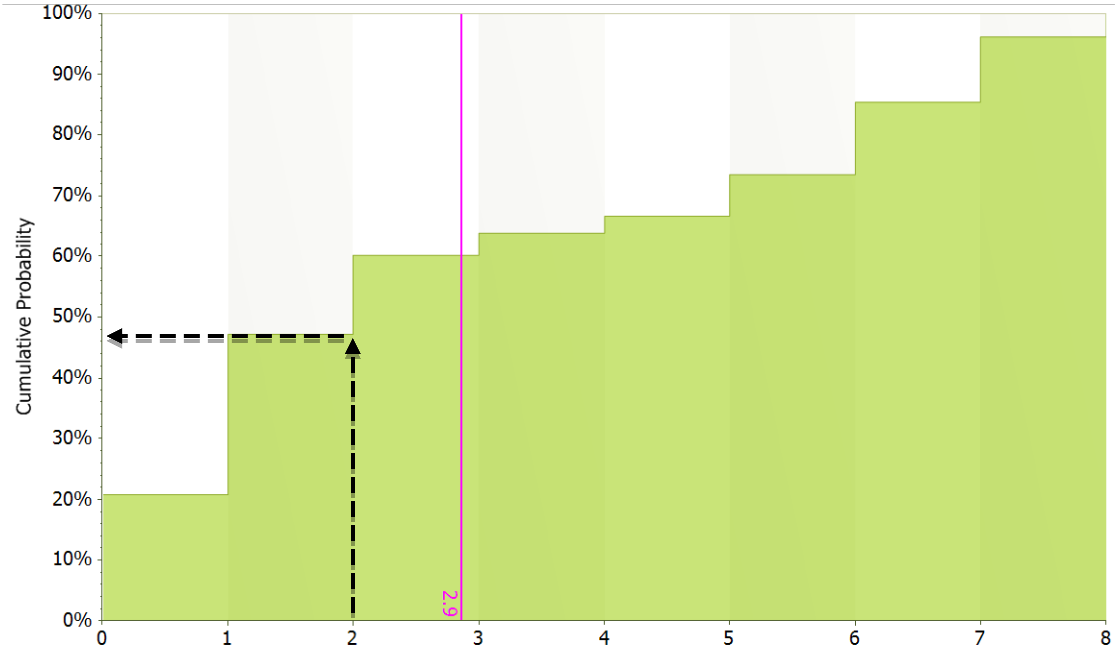


Figure 6.6 Cumulative probability distribution for the number of Environment Agency outputs achieving 'better than now' in the MMD model

The mean of this distribution is shown by the red vertical line, so in other words, the average number of Environment Agency outputs expected to achieve 'better than now' is three out of eight. The green shaded region is the cumulative probability; for example, there is a significant chance (almost 50%) of two or fewer outputs achieving 'better than now', as shown by the dotted arrows.

A valuable use of the model is to now identify which nodes have the biggest impact on this probability distribution, because they are likely to be the highest priorities for any future interventions. DPL can generate a Tornado diagram automatically (Figure 6.7).

The vertical line on the Tornado diagram shows the average number of outcomes that achieve 'better than now' with the base case probability values (an average of just less than three outcomes). The bars show how this number varies if it was possible to control with certainty which state each node is actually in.

For example, the base case probabilities for the Local and National Models node (Out6) are 36% chance 'better than now' and 64% chance 'same as now' (see Figure 6.5). The top bar tells us that, if it is possible to change these probabilities to be 100% chance 'better than now' and 0% chance 'same as now', then the mean number of Environment Agency outcomes achieved would increase to 6.1.

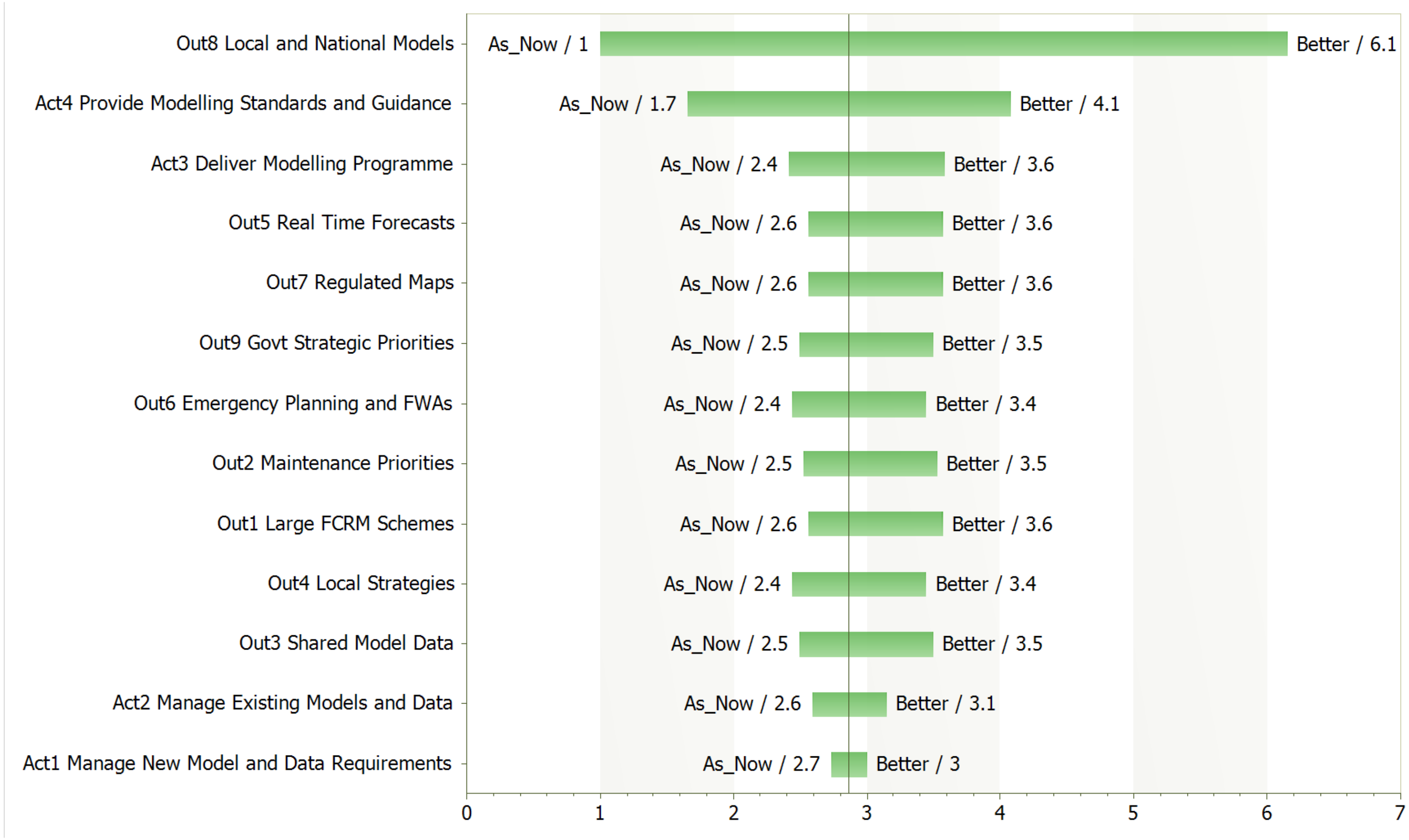


Figure 6.7 Tornado diagram showing MMD model sensitivity to each node

Not surprisingly, the Local and National Models node is the most sensitive because it links directly to all eight Environment Agency output nodes. This node is itself dependent on two other nodes:

- the activities to provide modelling standards and guidance (Act4)
- the activities related to delivering the modelling programme (Act3)

The Tornado diagram shows that the modelling standards and guidance activities are the most sensitive of these – it has the larger bar.

It could be concluded from this simple example that an intervention to increase the probability of Local and National Models achieving their 'better than now' state would deliver a significant benefit – and perhaps the most important activity to try and improve first would be the provision of modelling standards and guidance.

6.3 SCE quantified model

6.3.1 Simplified SCE model

The final simplified SCE model used for the quantification exercise is shown in Figure 6.8. This representation shows that the six Environment Agency outcomes in pink each depend on an engagement activity and that these in turn depend on some strategic and specific community engagement planning.

The nodes labelled R and K in Figure 6.8 are external to the SCE model. This model is also different to the MMD model in that it has two switch nodes labelled D and S that have the effect of scaling the assessed probability values by a fixed multiplier. For example, if a community has not had a flood in the past or has not had any previous engagement, then the probability of achieving 'better than now' for a number of the dependencies is judged to be lower. The probability values assessed for each dependency are listed in Appendix 3 (available on request by emailing fcerm.evidence@environment-agency.gov.uk).

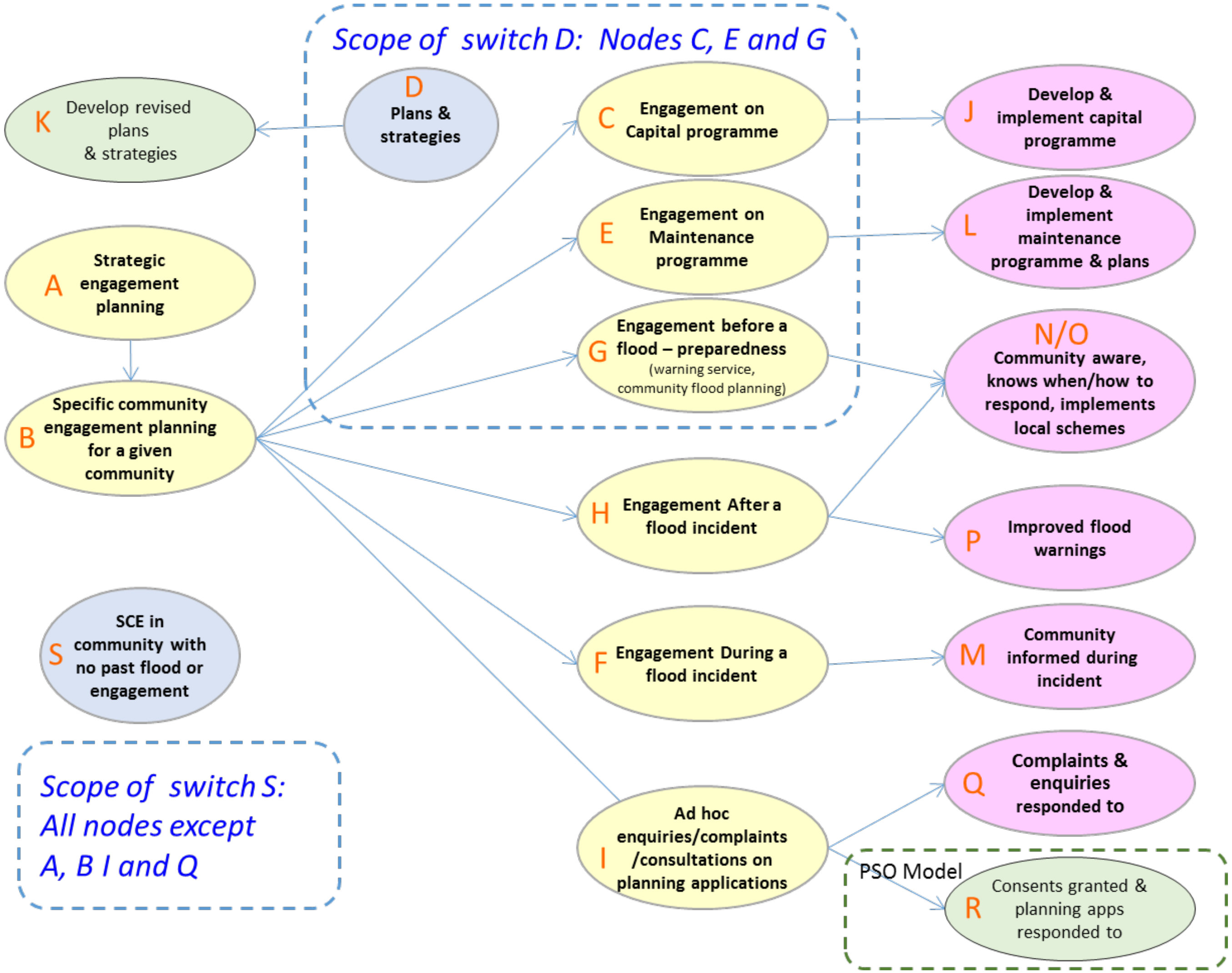


Figure 6.8 Final simplified SCE model used for quantification

6.3.2 SCE model results

Figure 6.9 shows the overall probability values for the output nodes in the model (the six pink Environment Agency outputs in Figure 6.8 plus node R). These values are with the switch settings set to S = 'No previous flood or engagement in the community' and D = 'There has been previous engagement on plans and strategies in that community'.

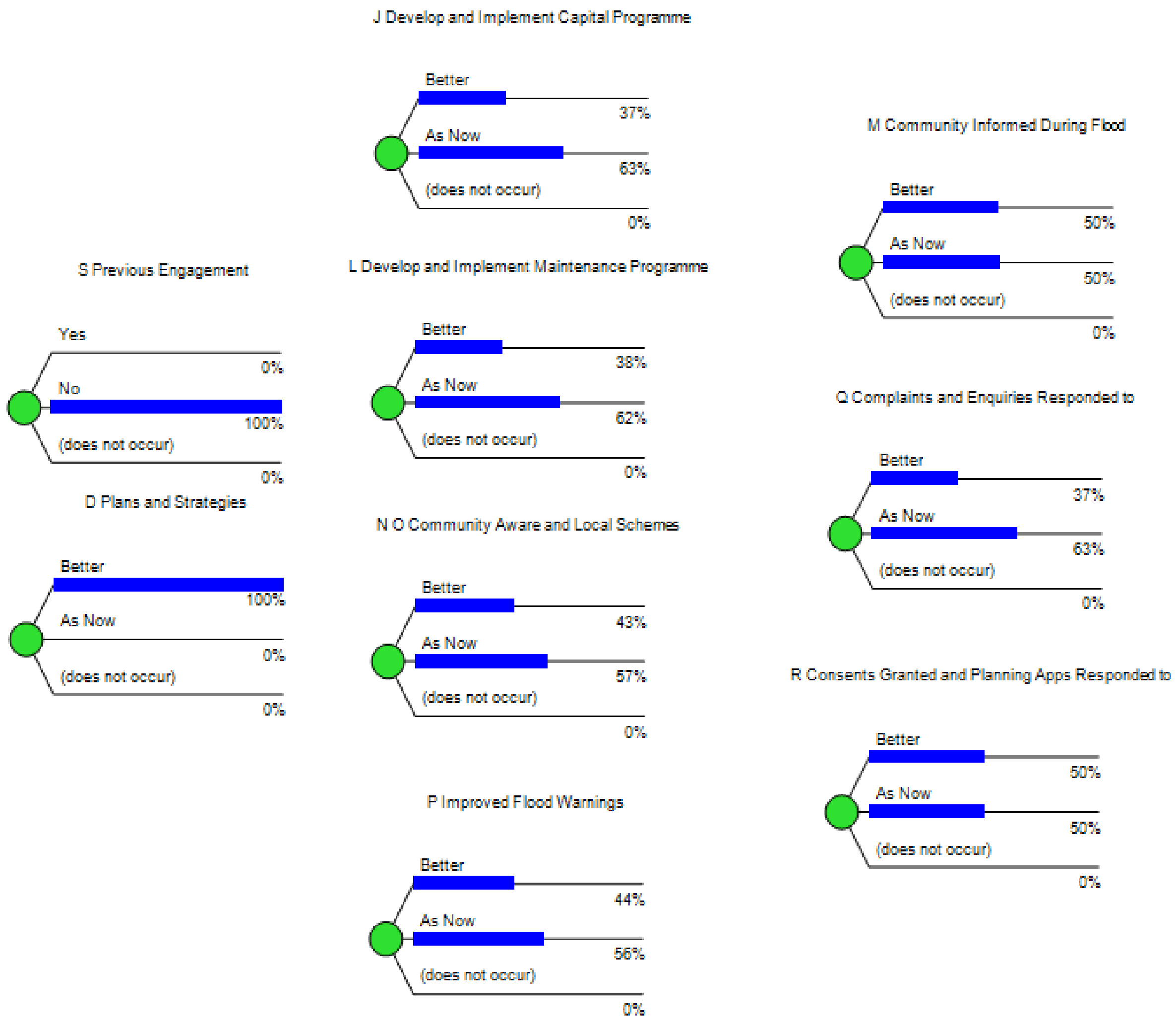


Figure 6.9 Overall probability values for the output nodes in the SCE model, based on the switch settings for nodes S and D as shown

Figure 6.9 shows that, with no previous engagement and no previous experience of flooding, most of the output nodes have a less than 50% chance of achieving 'better than now' without some further intervention.

The cumulative probability distribution is shown in Figure 6.10. The average number of Environment Agency outputs expected to achieve 'better than now' using the base case probability assessment is between two and three (out of six).

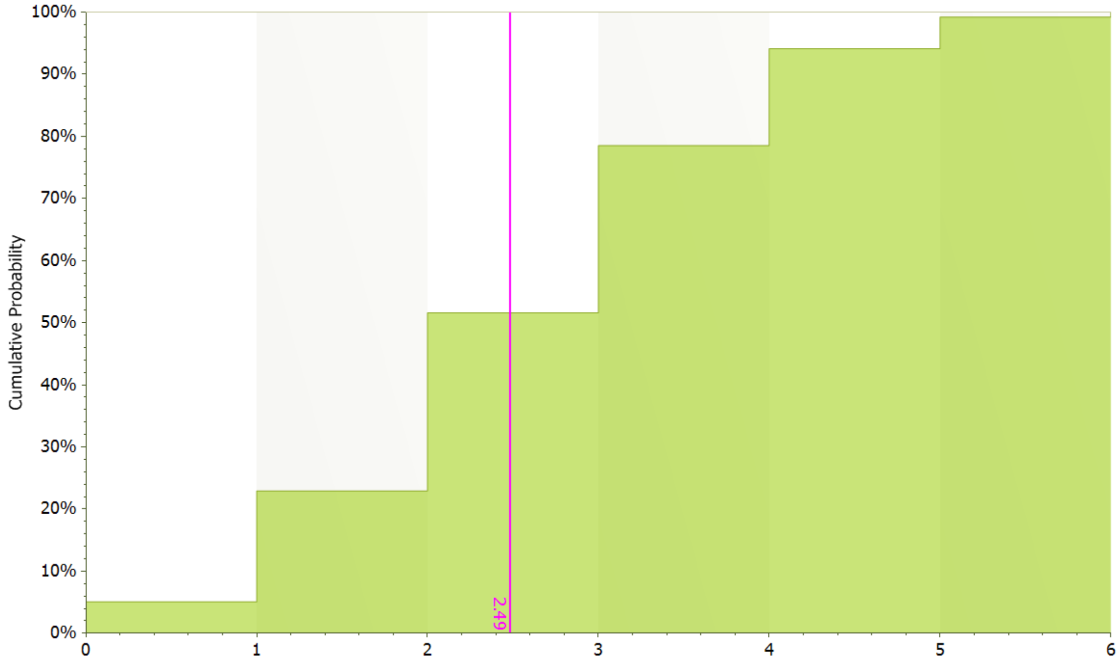


Figure 6.10 Cumulative probability distribution for the number of Environment Agency outputs achieving 'better than now' in the SCE model

The Tornado diagram for the SCE model (Figure 6.11) shows that the most sensitive activity node is node B, Specific Community Engagement Planning. An intervention to increase the probability to 100% of node B achieving 'better than now' status would have the biggest impact on the average number of outcomes achieved, increasing the mean value from 2.5 to 2.9. The same 'upside' is achieved by moving node I, Ad hoc Activities, to 'better than now'. However, investing in node B also has the benefit of protecting against a bigger 'downside' where, if B remains 'As now', the average number of outputs achieving 'better' falls to 1.9.

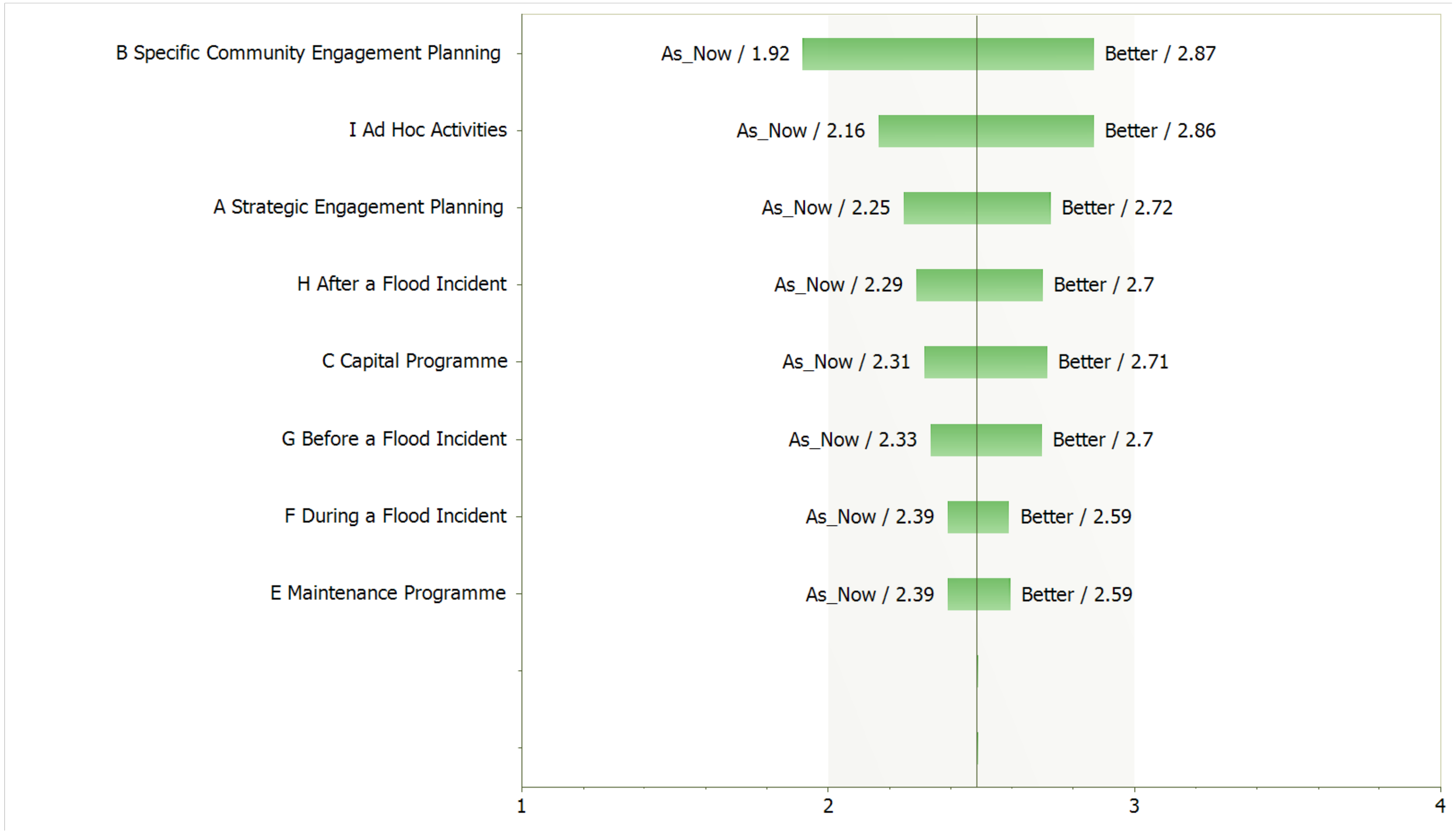


Figure 6.11 Tornado diagram showing SCE model sensitivity to each activity node

6.4 Taking the models forward

The qualitative models often provide most of the benefit from a dependency mapping exercise. In this case, the models communicate how important MMD and SCE activities are to the achievement of many Environment Agency outcomes by drawing direct lines of dependency between activities and outcomes. They are likely to be useful for MMD and SCE staff to explain what they do to a wider audience, for example, to other parts of the Environment Agency or to the Department for Environment, Food and Rural Affairs (Defra).

Quantitative versions of the models have also been developed to show how they can be used to give insight into the most important dependencies and hence identify priorities for interventions. However, the models presented here are simple and the probability data used to parameterise them are based on a small group using expert opinion only. In the longer term, it would be possible to:

- improve confidence in the probability data by consulting more people and gathering better evidence to support the expert opinion data
- extend the scope of the models by adding more detailed nodes for areas of activity that seem to be the most important
- add quantified costs and benefits to the model

How the models could be extended to include a cost–benefit assessment is described below.

6.4.1 Cost–benefit assessment using a dependency model

The dependency models can be further extended using the DPL software to give a cost–benefit assessment.

The first step is to add a cost–benefit decision node to the quantitative model. In DPL a decision node is represented by a yellow box, as shown in Figure 6.12 for the MMD model.

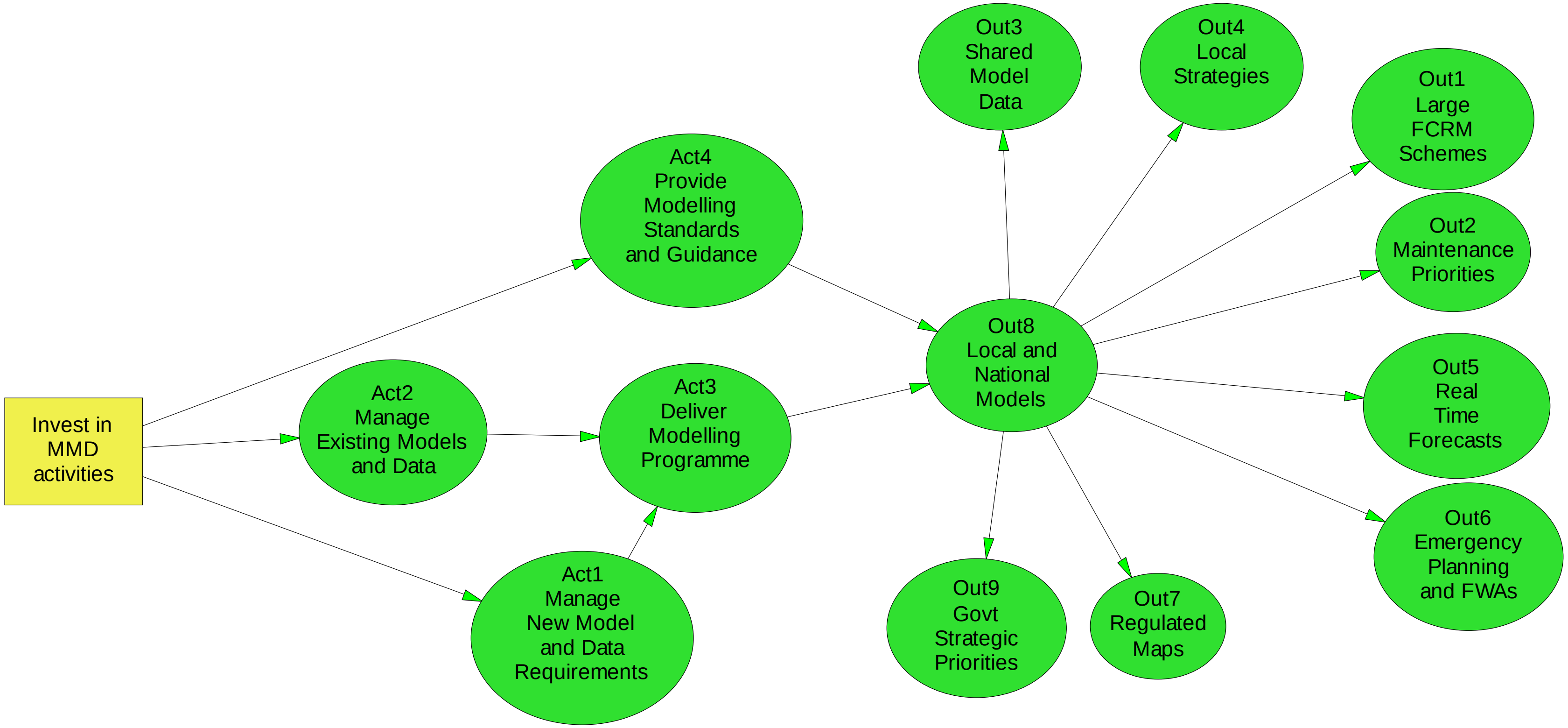


Figure 6.12 Addition of a cost–benefit decision node to the MMD model

The cost–benefit decision modelled here is the choice of whether or not to invest more resources in MMD activities. Hence, the possible states for the decision node are:

- Decide to invest more resources in MMD activities
- Decide to maintain resources at current levels

An arrow has been added between the investment decision and the three input activity nodes (Act1 to Act3) to signify that the decision affects the probability of these three nodes achieving their 'better than now' state. The dependency for Act4 is shown in Figure 6.13 as an example.

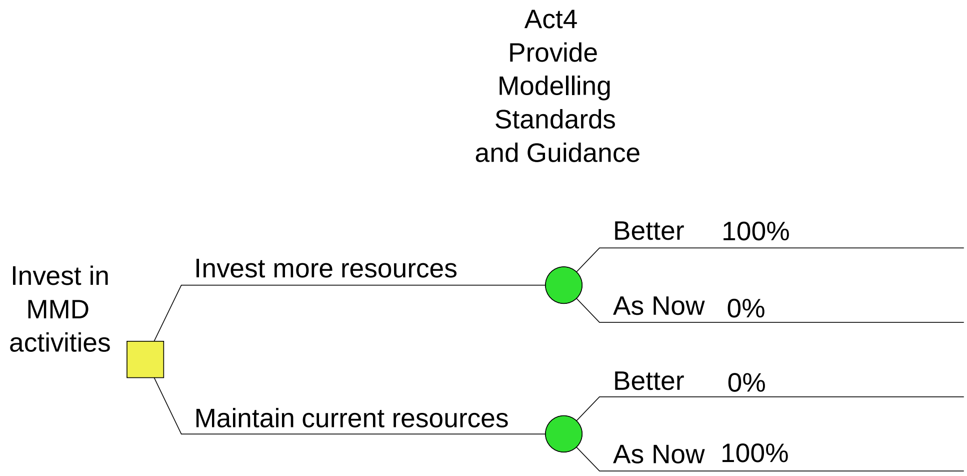


Figure 6.13 Dependency of Activity 4 (Act4) on the investment decision

Figure 6.13 shows that deciding to 'invest more resources' means that the activity 'Modelling Standards and Guidance' will definitely achieve the desired outcome (100% probability that the 'better than now' state is achieved).

The final step is to specify benefit and cost values for each node. The decision to invest in MMD activities triggers a definite cost for each activity node. However, the benefits are uncertain because they depend on the probability of each output node achieving its 'better than now' state.

Table 6.2 lists the fabricated benefit and cost values used for each node in the illustration prepared for this report. Running the model with these data generates a cumulative probability distribution for total net benefit (benefits minus costs) for each decision alternative, as shown in Figure 6.14.

Table 6.2 Fabricated benefit and cost figures used to illustrate the cost–benefit assessment

	Incremental benefits from achieving 'better than now'
Output 1: Large FCERM scheme proposals	1000
Output 2: Maintenance priorities	500
Output 3: Shared model data and advice	100
Output 4: Local strategies	100
Output 5: Real time forecasts and warnings	500
Output 6: Emergency planning and Flood Warning Areas	200
Output 7: Regulated maps	500
Output 8: Local and national models	100
Output 9: Strategic priorities and investment needs for government	200
	Incremental costs of investment decision
Activity 1: Manage new model and data requirements	100
Activity 2: Manage existing models and data	300
Activity 3: Deliver modelling programme	100
Activity 4: Provide modelling standards and guidance	200

Notes: The costs and benefits are fabricated numbers without any units specified, but it would be a simple exercise to re-run the model with actual costs and benefits specified in £.

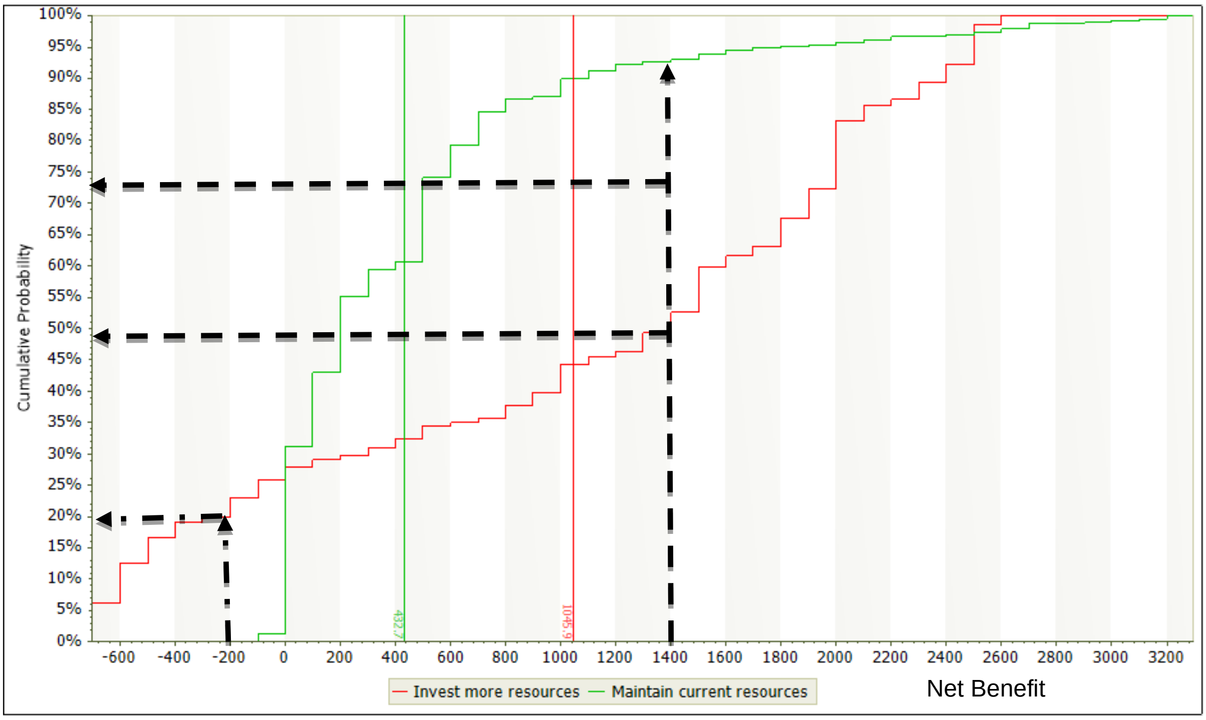


Figure 6.14 Cumulative probability distribution for total net benefit for the two decision alternatives (invest more resources or maintain current resources)

The cumulative probability curve can be interpreted by looking at the black dotted lines in Figure 6.14 for any particular net benefit. For example, for a net benefit of 1400, the probability read off from the red or green curve is the chance that the net benefit is less than this value. The intersection with the green curve shows that there is just over a 90% chance that the net benefit will be less than 1400 units, or put another way only a 10% chance that the net benefits will be greater than 1400 units under the 'maintain current resources' decision. The intersection with the red curve shows that there is just under a 50% chance that the net benefits will be less than 1400 units, or put another way a greater than 50% chance that the net benefits will be greater than 1400 units under the 'invest more resources' decision. The relative steepness of the early part of the green curve therefore indicates that the probability of achieving high benefits (greater than 1400) is quite small.

The curve for the 'invest more resources' decision alternative also has an average, or expected value, net benefit of 1045.9 units (shown by the vertical red line). This is higher than the expected value net benefit of 432.7 units for 'maintain current resources'. So based on the expected value, the optimum decision is to make the investment. The total cost for the investment is 700 units (Table 6.2), so the benefit to cost ratio is 1.49 (1045.9/700). However, the red curve also shows that there is a 20% chance that the net benefits for the 'invest more resources' case will be –200 or less, that is, the extra benefits achieved will not outweigh the costs.

This result illustrates the importance of sensitivity analysis, especially to check the sensitivity of the cost–benefit assessment to the node probability values. Figure 6.15 shows the Tornado diagram for the updated model.

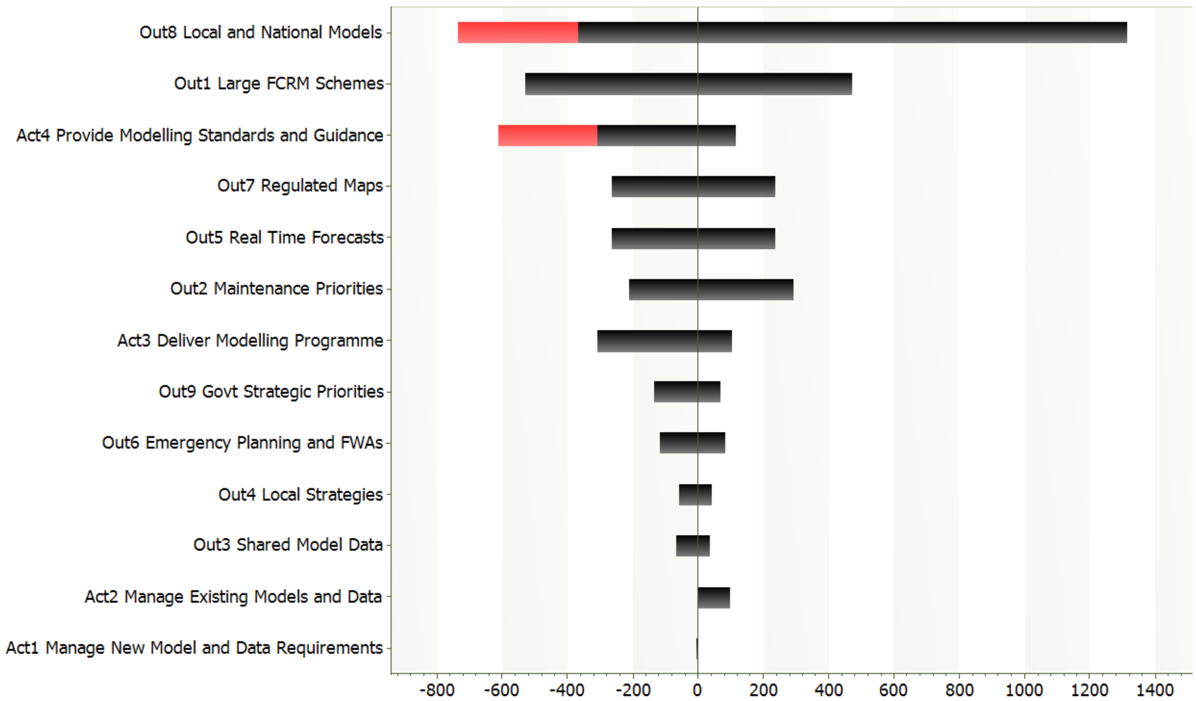


Figure 6.15 Tornado diagram for MMD model with fabricated cost–benefit data

The x-axis scale in Figure 6.15 shows how the expected value for the 'invest more resources' decision option would change if the probability of each node in turn could be controlled; for example, the bar for Activity 4 extends from –613 units to +112 units. This means that the expected value net benefit would decrease by 613 units if the probability of achieving the 'better than now' state for Activity 4 was 0% and it would increase by 112 units if the probability of achieving the 'better than now' state was 100%. The two bars with the red tips would change the optimum decision to 'maintain current resources' if the probability of achieving 'better than now' really was 0% for these nodes.

In this hypothetical case, the Environment Agency should therefore consider what additional actions it can take to improve the chances that Activity 4 (Provide Modelling Standards and Guidance) and Output 8 (Local and National Models) do actually achieve their 'better than now' state when the investment in MMD activities is made. For Activity 4, the maximum potential gain is 112 units so this is the most that the Environment Agency should be prepared to spend to ensure that 'better than now' is achieved.

7 Conclusions

The project has demonstrated the strength of dependency modelling, and in particular the modelling process, in building a depth of understanding among participants of the complex relationships between FCERM activities and outcomes, and how the models can be used to help communicate these relationships.

Each part of the process contributed to the overall value, building understanding in stages.

In the MMD area, the qualitative models have already been used to help communicate the central importance of modelling, mapping and data activities to understanding and effectively managing flood risk. The SCE model development led to valuable discussion between engagement and communications specialists from across the Environment Agency of how and where SCE activities affect FCERM outcomes.

The process of state definition involved structured discussions of the ways in which activities and outputs could be improved to improve outcomes. This drew on the varied experiences of the different members of the groups. The state definitions provide a ‘long list’ of possible ways to improve the effectiveness of activities.

Quantification of the model has allowed identification of those activities that contribute most to outputs. For example, from the simple exercise carried out here, it can be concluded that, in the MMD area:

- an intervention to increase the probability of local and national models achieving their ‘better than now’ state would achieve considerable benefit
- perhaps the most important activity to try and improve first would be the provision of modelling standards and guidance

The SCE model has shown that, in communities where there has not been recent engagement or which have not previously been affected by flooding, without investing in engagement improvements there are unlikely to be improvements in:

- the development and implementation of the capital and maintenance programmes
- flood warnings or community awareness and action
- customer enquiries and complaints

Improving the specific community engagement planning activity results in the greatest improvements to the outputs listed above.

Quantification of the modelling can be taken further in a number of ways.

- Scaling factors that express the relative importance of each of the modelled outputs in terms of achieving outcomes can be used to prioritise activities on the basis of their contribution to outcomes. This will provide a basis for prioritising possible improvements to activities based on their efficacy.
- The level of detail of the quantified models can be developed in those areas that have most impact on outcomes. This will improve the precision and utility of the modelling.
- The model can be linked to a cost–benefit analysis to:
    - quantify the value of the various activities and outputs to the outcomes

- provide a basis for prioritising improvement actions on the basis of their cost-effectiveness

The MMD and SCE models are currently being used as template examples in a dependency modelling exercise for the whole of FCERM to assess the potential implications of the 2015 spending review on FCERM outcomes. At the time of writing, the qualitative models are being finalised and the quantification stage is about to begin. The quantification stage will use the cost–benefit methodology outlined in this report.

8 Recommendations

Recommendation 1

The qualitative maps are of considerable benefit. MMD and SCE staff should continue to develop them as ‘live’ documents to help them communicate widely within the Environment Agency and externally how their activities contribute to flood and coastal erosion risk management outcomes.

Recommendation 2

The quantitative models developed at this stage are simple yet demonstrate the principles. The Environment Agency should continue to improve these models by:

- consulting more widely to add detail to the models and refine the node probability estimates
- gathering cost and benefit data to make use of the cost–benefit assessment capabilities of the software

Recommendation 3

The journey for the participants is just as valuable as the end models. Other Environment Agency teams should adopt this approach to understand how their activities contribute to Environment Agency outcomes. A similar exercise is already taking place as part of the 2015 Spending Review discussions between the Environment Agency and Defra.

Recommendation 4

The act of defining the ‘same as now’ and ‘better than now’ states for each of the nodes provides a powerful way of identifying potential improvements focused on what will achieve better outcomes, even in the absence of further quantification. Model development should be taken at least to this stage in each case.

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List of abbreviations

CCRA	Climate Change Risk Assessment [UK]
CFMP	Catchment Flood Management Plan
CBA	cost–benefit analysis
DPL	decision tree software package
FCERM	Flood and Coastal Erosion Risk Management
FRA	Flood Risk Assessment
FRMP	Flood Risk Management Plan
FWA	flood warning area
FWD	Floodline Warnings Direct
GHG	greenhouse gas
IDB	Internal Drainage Board
LTIS	Long-term Investment Scenarios Study (Environment Agency 2014)
MMD	modelling, mapping and data
NaFRA	National Flood Risk Assessment
PESTLE	Political, Economic, Social, Technological, Legal and Environmental influences [structure used to facilitate thinking around an organisation's external macro environment]
PSO	Partnership & Strategic Overview [team in the Environment Agency]
SCE	stakeholder and community engagement
SMP	Shoreline Management Plan
WWO	Working with Others

Glossary of terms

Capital scheme	See FCERM capital scheme below.
Catchment Flood Management Plan	A strategic planning document developed by the Environment Agency together with other main decision makers within a river catchment to plan and agree the most effective way to manage flood risk in the future. (A catchment is an area that serves a river with rainwater. In other words, every part of land where the rainfall drains to a single river is in the same catchment.) Shoreline Management Plans (see below) consider flooding from the sea.
Conditional probability	The probability of an event occurring given (the condition that) some other event has occurred.
Cost–benefit analysis (CBA)	A technique for assessing the monetary social costs and benefits of an investment or activity over a given time period.
Dependant	An entity upon which another depends.
Dependency	A causal relationship from an entity to its dependant.
Dependency models	Dependency models are also known as Bayesian belief nets, belief networks, influence diagrams, causal maps, causal probability models and directed acyclic graphs. One useful description is: 'graphical models that use probabilistic expressions to describe the relationships among variables. They are able to explore and display causal relationships between key factors and final outcomes of a system in a straightforward and easily understood manner' (Pollino and Hart 2008).
DPL	A user-friendly decision analysis tool from Syncopation, based on Microsoft® Excel.
Entity (variable)	A node in a dependency model network.
FCERM capital scheme, FCERM scheme or flood scheme	Physical measures to address the flood and coastal erosion risk to communities and property. The measures needed for each location are considered on a case by case basis. Some of the measures that may be considered include: • building flood and coastal defences • flood storage reservoirs • land management • portable defences
Impact	The resulting effects if an uncertain event X occurs, measured in cost, injury or other dimensions.
Maintenance programme	The Environment Agency's maintenance programme sets out the maintenance work that it does:

	• every year (frequent maintenance) • every few years (intermittent maintenance) Examples of activities in the programme include: • maintaining flood barriers and pumping stations • clearing grills and removing obstructions from rivers • controlling aquatic weed in rivers • managing grass, trees and bushes on flood embankments • inspecting and repairing flood defence structures
Maintenance protocol	The Environment Agency's maintenance protocol outlines the approach the Environment Agency takes to the maintenance of flood and coastal risk management assets. It describes how they will go about discontinuing permanently some activities that they have previously undertaken.
The National Flood Risk Assessment	Provides an indication of flood risk at a national level
Probability	The probability (likelihood) that an event X will occur is the number of instances when does occur expressed as a proportion of the instances when it could occur.
Regional Flood and Coastal Committee	A committee established by the Environment Agency under the Flood and Water Management Act 2010 that brings together members appointed by Lead Local Flood Authorities and independent members with relevant experience.
Shoreline Management Plan	A Shoreline Management Plan provides a large-scale assessment of the risks associated with coastal evolution and presents a policy framework to address these risks to people and the developed, historic and natural environment in a sustainable manner.

Annex 1: Participants in the project

Focus Group attendees

Name	Expert area
Lydia Burgess-Gamble	Project Manager
Rhiannon Clancy	SCE
Cath Eales	MMD – Project Executive
Jo Higgs	SCE
Stefan Laeger	Other
Louise Merritt	SCE
Mark Russell	MMD – Senior Business User
Harry Walton	Economist

Workshop 1

Name	Expert area
Lydia Burgess-Gamble	Project Manager
Adam Daniells	SCE
Cath Eales	MMD
Jamie Fielding	SCE
Emma Harding	Economist
Jo Higgs	SCE
Rhys Hobbs	MMD
Laura Littleton	SCE
Rob Lunt	SCE
Rachael McMahon	SCE
Louise Merritt	SCE
Mark Russell	MMD
Mike Steel	MMD

Name	Expert area
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Tom Toogood	MMD
Sarah Underhay	SCE

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Name	Expert area
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Andy Brown	MMD
Lydia Burgess-Gamble	Project Manager
Jonathan Chapman	Other
Cath Eales	MMD
Jamie Fielding	SCE
Emma Harding	Economist
Jo Higgs	SCE
Rhys Hobbs	MMD
Laura Littleton	SCE
Rob Lunt	SCE
Louise Merritt	SCE
Mike Mombrun	MMD
Andy Moores	Other
Mark Russell	MMD
Mike Steel	MMD
Tom Toogood	MMD

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Name	Expert area
Lydia Burgess-Gamble	Project Manager
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Emma Harding	Economist
Jo Higgs	SCE
Louise Merritt	SCE
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Cath Eales	MMD
Elizabeth Frazer	SCE
Emma Harding	Economist
Jo Higgs	SCE
Laura Littleton	SCE
Louise Merritt	SCE
Ian Miller	Other
Mark Russell	MMD
Mike Steel	MMD
Tom Toogood	MMD

SCE webinar

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Kevin Barnes	SCE
Sarah Bouet	SCE
Lydia Burgess-Gamble	Project Manager
Adam Daniells	SCE
Jamie Fielding	SCE
Elizabeth Frazer	SCE
Emma Harding	Economist
Jo Higgs	SCE
Laura Littleton	SCE
Rob Lunt	SCE
Rachael McMahon	SCE
Louise Merritt	SCE

MMD webinar

Name	Expert area
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Cath Eales	MMD
Emma Harding	Economist
Rhys Hobbs	MMD
Mark Russell	MMD
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