DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS **CSG 15**

Research and Development

Final Project Report

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Executive summary (maximum 2 sides A4)

The major project output 'Scoping the Broad Scale Modelling Hydrology Programme' (February 2002) has the following executive summary:

This report presents a strategic vision for the hydrological programme of the Broad Scale Modelling Theme of the DEFRA / Environment Agency Flood Management Research Programme over a five to ten year time span.

It can be read in conjunction with the 'Hydrology Vision' statement (Calver and Anderson, 2002) which offers a succinct outline framework for hydrological flood management R&D across all DEFRA / Environment Agency Themes

Chapter 1 sets the context and terms of reference for developing this hydrological research programme. Chapter 2 describes user needs and the requirements of a Broad Scale Modelling (BSM) hydrological research agenda. The scientific and technical background is presented in Chapter 3. Chapter 4 outlines research initiatives of other organizations of relevance to BSM hydrology.

Building on the information of Chapters 2 and 3, the BSM hydrological research strategic programme is presented in Chapter 5. Its eight major components are described, the relationships between them identified in terms of subject matter and of timing, and their five year indicative budget outlined. The components are identified as:-

1 Definition of strategic agenda
2 Maintenance of current practice
3 National spatial-temporal rainfall modelling
4 National continuous simulation runoff modelling
5 Modelling impacts of land use and land management change
6 Climate impact modelling
7 Building a new modelling capability
8 Software production

It is estimated that an approximate budget of £9.4 million is required to meet the BSM objectives over a five year period, but that part of this could come from research partnerships with industry and the research councils.

The report concludes, in Chapter 6, with recommendations for effective uptake of the BSM strategic hydrological programme in the context of a continuing need for effective flood management research.

Appendices provide project outlines from the September 2001 BSM Targeted Programme, a note on the consultation process for this Strategic Programme and comment on research emphases.

Scientific report (maximum 20 sides A4)

The final report 'Scoping the Broad Scale Modelling Hydrology Programme' has been submitted under separate cover and will also be available on DEFRA-EA web sites. Part of this report is reproduced below.

5. STRATEGIC PROGRAMME FOR BSM HYDROLOGY

The 1999 Penning-Rowsell report introduced a changed grouping of flood and coastal defence research categories from traditional subject matter groups to cross-cutting classifications: BSM, for example, covers hydrology, river hydraulics, coastal hydraulics, ecological and socio-economic modelling. The six themes are reiterated in Table 5.1, together with major areas of hydrological linkage with BSM. Building on the users' requirements of Chapter 2 of this report and the scientific and technical background of Chapter 3, we present here an analysis of the R&D needs of BSM hydrology. There is strong overlap with the interests of other themes, which is inevitable, given the nature of the thematic structure, if an integrated flood management R&D programme is to be developed. The precise definition of funding responsibilities is a management issue not considered further here (although we note that discussions are, for example, proceeding with FECP Theme concerning aspects of land management research). Table 5.1 also serves to reiterate the drivers and clients of BSM (Chapter 1). Broad Scale Modelling has very strong methodological and tool-building components, leading to application of these tools within and beyond BSM Theme.

A five year programme of research is defined within the context of a broader ten year vision. This five year programme is in our view a minimum requirement to support the aims of BSM as currently specified on that time scale, namely development of a nationally applicable BSM methodology. The ten year vision indicates the continuing need for development and maintenance of appropriate tools, building on scientific and technical advances. The programme components are defined with varying degrees of confidence with respect to scope and cost. For those core components which build on an existing programme of work, a three year programme can be relatively tightly specified and costed, and a five year budget estimated with a fair degree of confidence. For other components, complex research issues are raised which require preliminary work and particularly careful consideration, involving consultation with key researchers in the respective fields. For these we have tightly specified an initial, scoping phase of work. Whilst not wishing to preempt the results of those studies, we have made preliminary estimates based on our judgement of the needs so that an indication of the overall magnitude of the scope and cost of the five year programme can be estimated: these are, however, indicative only.

Some of the programme elements address national issues where it may be considered that there are shared responsibilities. For example, we consider urban flooding, which is already the subject of water industry interest. Similarly, aspects of work require development of the science base, with respect to experimental research and information technology, and this is a concern of the Research Councils. In such areas it may be appropriate for DEFRA and the Environment Agency to establish dialogues with a view to moving forward in partnership at the national (or European) level, as indicated in Chapter 4.

Table 5.1 DEFRA / Environment Agency Flood Management R&D Themes in terms of their main linkages with BSM hydrology

Fluvial, Estuarine and Coastal Processes (FECP)	• Hydrological process knowledge (natural and man-made environments) as basis of good model structure. • Theme in which Flood Estimation Handbook research currently resides.
Policy Development (PD)	• Overarching driver and client of BSM planning tools.
Broad Scale Modelling (BSM)	• CORE INTEGRATED HYDROLOGICAL MODELLING. • Within-theme linkage to river hydraulic modelling, ecological modelling and socio-economic modelling.
Flood forecasting and warning (FFW)	• Some modelling techniques and data potentially common to BSM flood frequency estimation (though used in different manner).
Risk Evaluation and Understanding of Uncertainty (REUU)	• Data issues relevant to hydrology currently covered in this theme. • Climate change a key remit; application of scenarios for impact assessment well-suited to modelling environment of BSM. • Uncertainty, trend and risk analyses remit also effectively pursued in a BSM environment.
Engineering (ENG)	• Uptake of BSM serves hard and soft engineering solutions.

The Hydrology Strategic Programme (HSP) of BSM research has eight major components: these are not necessarily individual projects but are groups of activities serving common aims. These components are:-

1 *Definition of strategic agenda*
2 *Maintenance of current practice*
3 *National spatial-temporal rainfall modelling*
4 *National continuous simulation runoff modelling*
5 *Land management and hydrological impact modelling*
6 *Climate impact modelling*
7 *Building a new modelling capability*
   7a Generic modelling techniques
   7b Specification of data requirements for modelling
   7c IT framework
8 *Software production*

In Table 5.2, these components are mapped against the next ten years, with the presence of a symbol against a component indicating activity in the particular financial year. Plainly, such a table can be only indicative, but it does serve to indicate dependencies and emphases of research activities. These interactions are described in the sections on the individual components which follow below in this chapter.

In Table 5.2, the zones shaded in grey indicate areas of research for which the Stage 1 Targeted Programme of this scoping study provided project definitions. The numbers in brackets after the component title refer to the numbers of those project specifications, which are given in Appendix 1. Original specification '1a' has been developed into project FD2105, and '2a' into FD2106.

In a similar manner to exchanges of hydrological information between the flood management Themes, liaison between components of BSM is plainly essential to forge efficient links in both methodological and application research. An example illustrating the importance of these linkages is afforded by the need for flood risk mapping. All components of BSM hydrology are of relevance; other strands of BSM (particularly hydraulics and socio-economics) enhance risk mapping, and all six R&D Themes contributed (directly or indirectly) to, or use, the tools.

Table 5.2 The Components of the BSM Hydrology Strategic Programme with indicative cost levels and linkages in time

HSP COMPONENT	2002 -03	2003 -04	2004 -05	2005 -06	2006 -07	2007 -08	2008 -09	2009 -10	2010 -11	2011 -12	2002-07 budget £ million
C1 Definition of strategic agenda	** Stage 2			** Stage 3		* Stage 4					0.1
C2 Maintenance of current practice	*	*	*	*	*				*	*	0.5
C3 National spatial-temporal rainfall modelling (1a)	**	**	**	**	**		*	*			1.0
C4 National continuous simulation runoff modelling (2a)	**	**	**	**	**		*	*			1.3
C5 Modelling impacts of land use and land management change (3a, 3b, 3c)	*	***	**	**				**	*		2.4
C6 Climate impact modelling (1b)	*	*	*	*				*			0.3
C7 Building a new modelling capability											
(a) generic modelling techniques		*	*	*	*	*	*	*	*	*	0.8
(b) data and data assimilation	*	**	*	*	**	***		*		*	1.0
(c) IT framework	*	*	*	*	**	***		*		*	0.8
C8 Software production		*	**	**	*	*	**	*	*	*	1.2

There are two important points to note about funding levels. First, the star symbols in the boxes give an indication of relative levels of funding which it may be considered appropriate for DEFRA / Environment Agency to commit to the HSP Components: * indicates a modest funding level, ** a medium, and *** a high level of investment. Second, the right-hand column shows the indicative budget to achieve DEFRA / Environment Agency BSM HSP aims for the **five year** programme (i.e. the 2002-2007 sector of the table). This totals £9.4 million. This figure differs from that indicated by the symbols described above in that, as noted earlier, the five year overall budget is unlikely to be a DEFRA / Environment Agency responsibility alone (*cf.* the other research initiatives described in Chapter 4 above). Recall, also, that flood hydrology research is also funded by some of the other themes (for example, data issues and aspects of uncertainty in REUU Theme). The budget figures are necessarily highly speculative: they are presented to give an overall indication of requirement, and the figure is confined to the five year timescale since uncertainties increase markedly in the longer time-frame.

Following discussion with BSM Theme Leader, a possible pattern of funding is shown below in Table 5.3, indicative of the principle of aligned funding.

Table 5.3 The Components of the BSM Hydrology Strategic Programme with possible funding sources

HSP COMPONENT	2002-07 budget £ million	DEFRA/EA core funding	DEFRA/EA – Research Council - others partnerships	DEFRA/EA – commercial partnerships
C1 Definition of strategic agenda	0.1	0.1		
C2 Maintenance of current practice	0.5	0.5		
C3 National spatial-temporal rainfall modelling (1a)	1.0	1.0		
C4 National continuous simulation runoff modelling (2a)	1.3	1.3		
C5 Modelling impacts of land use and land management change (3a, 3b, 3c)	2.4	1.2	1.2	
C6 Climate impact modelling (1b)	0.3	0.3		
C7 Building a new modelling capability				
(a) generic modelling techniques	0.8	0.2	0.6	
(b) data and data assimilation	1.0	0.4	0.6	
(c) IT framework	0.8	0.2		0.6
C8 Software production	1.2			1.2
Total	9.4	5.2	2.4	1.8

Figure 5.1 outlines key interactions between the Components of the BSM Hydrology Strategic Programme (and not necessarily data flows). The figure is simplified and the interactions are recognized to be very much more complex in terms of feedbacks and in terms of emphases in time.

Components 3, 4, 5 and 6 constitute the major area of hydrological modelling *per se*. Linking to these Components is Component 7 which deals with the development of the BSM modelling capability from research level outputs. This covers cross-cutting generic modelling techniques, data and data assimilation, and IT framework considerations. It in turn feeds into software production for flood management users (Component 8).

To the right of the Components 3 to 6 group in Figure 5.1 is the linkage with ‘current practice’. The description of Component 2 below indicates that over a ten year span ‘current practice’ is likely to change, such that at an early stage BSM research activities parallel, for example, Flood Estimation Handbook use (as in Catchment Flood Management Plans), while the ‘current practice’ of a later stage may see an increased modelling emphasis. Component 2 is identified to make clear the link between research and its dissemination and uptake by the user community, whatever the precise methodological nature of recommended practice.

Components 2–8 are not only influenced by Component 1, the strategic agenda; they in turn provide a feedback to how that agenda develops over time.

Within the Components 3 to 6 group, the outputs of Component 3 national spatial-temporal rainfall modelling provide an input to Components 4, 5 and 6 which are concerned with modelling the land phase of the hydrological cycle. Component 4 develops a national system of flood frequency estimation using continuous simulation including ungauged sites. Component 5 concentrates on impacts of land management on flooding, and Component 6 on impacts of climate variability or change on flooding.

In the remainder of this chapter the individual Components of the BSM Hydrology Strategic Programme are described.

Component 1 Definition of strategic agenda

This current study is charged with mapping out the strategy of the BSM hydrological agenda over a five to ten year period. This is necessarily done in the light of information currently available and an understanding of expected developments. Certain contingencies can be anticipated only in a general way, since R&D is a function not only of developments within (in this case) the hydrological field relative to flood management but of other issues affecting prioritisation of budgeting.

With this in mind, it is wise practice to review strategy from time to time: the timing indicated on Table 5.2 is indicative. Stage 3 and Stage 4 on the table follow on from this current Stage 2 activity. Stage 3 and subsequent reviews will have not only the forward-looking strategic remit; an important component will also be the appraisal of the projects ongoing and completed. A comparatively modest budget (unlikely to exceed £100k over five years) should ensure the aims of this component are met.

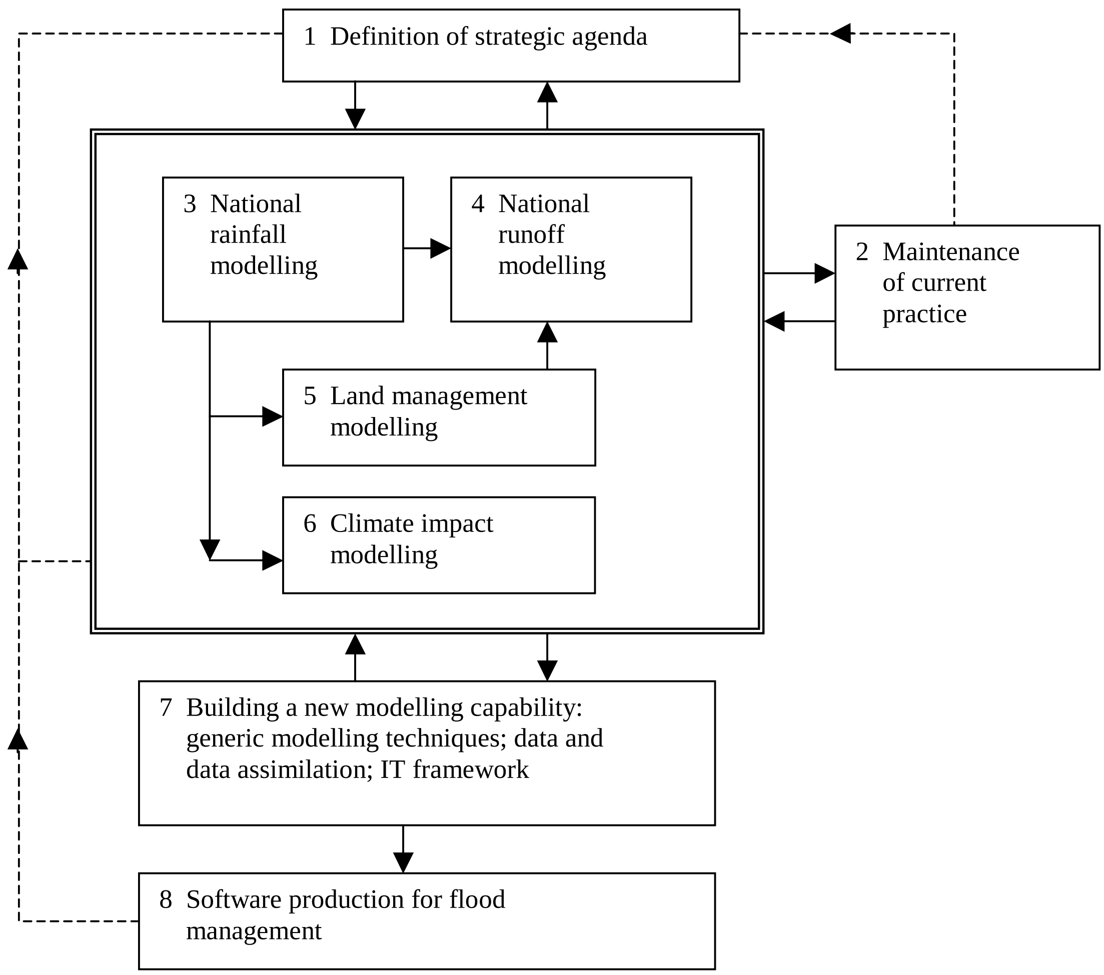

Figure 5.1 Generic linkages of components of the BSM Hydrology Strategic Programme (HSP)

The best basis for flood management R&D strategy combines the requirements of informed users with the potential that experienced researchers consider feasible and promising. The DEFRA / Environment Agency programmes are most profitably reviewed and defined to benefit from wider research initiatives.

Component 2 Maintenance of current practice

BSM hydrological methods, whilst well-recognised in the general hydrological research agenda, are, in terms of flood management tools, newly emerging. The weight of current *practice* therefore rests with statistical and event-based approaches which currently have an across-Theme setting. Flood Estimation Handbook research, for example, currently resides in the FECP Theme. A case where BSM is particularly responsible for the application of current flood frequency estimation techniques is in the context of Catchment Flood Management Plans (CFMPs). The Modular Decision Support Framework (MDSF), being developed at the time of writing to assist the development of CFMPs, seeks to allow exploration of impacts of land management and climate variability and is a system for national application in the period from 2001 to 2003.

Component 2 of the HSP therefore recognises that there is a requirement to service current flood estimation practice to meet broad-scale application aims in the short to medium term. This is a significant rather than major tranche of BSM funding. Looking to the latter part of a five to ten year outlook, the 'current' practice is likely to change, at least in emphasis, as BSM techniques become more widely used. By that time the development of continuous simulation systems will have been further researched and tested. The flavour, then, of Component 2 changes, from modification of *in situ* practice in meeting current aspirations, towards guidance and feedback on the migration towards additional or new methods. [In the context of other Themes, this process is demonstrated by the case of the Flood Estimation Handbook of 1999.] These uptake and dissemination items are, to a degree, part of the components handling applications. It is however important to put down a marker in Component 2 to cover the contingencies of experience of application: in the order of £0.5 million is budgeted over five years.

Component 3 Improved methods for national spatial-temporal rainfall and evaporation modelling for BSM

Component 3 deals with continuous rainfall modeling to overcome the shortcomings of current practice techniques and pave the way for continuous simulation approaches. As discussed above, continuous simulation hydrological modelling appears to be the most promising methodology to represent antecedent storm conditions and the effects of climate and land use change on catchment flood response. A basic requirement is the provision of continuous rainfall and evaporation time-series that preserve the extreme value properties of rainfall, and any interdependence of potential evaporation and rainfall. In addition, for whole catchment modelling, spatial properties of rainfall must be adequately represented. Current practice has several major limitations: a) rainfall is based on individual events, b) these are defined by standardized temporal profiles (which may fail to represent temporal properties of importance for specific applications), c) there is no adequate guidance as to the representation of spatial properties at large scale (a simple reduction factor is used to scale spatially uniform rainfall) and d) there is no current guidance for continuous simulation evaporation modelling.

Component 3 has therefore been designed to: i) provide continuous rainfall and evaporation time-series inputs for BSM, with appropriate spatio-temporal structure, ii) analyze catchment response to spatial rainfall as a function of spatial scale and rainfall type and hence produce guidelines for spatial-temporal model application, and iii) validate the spatially-distributed rainfall and rainfall-runoff modelling procedures

Building on previous MAFF-funded research, Component 3 will deliver:- a national procedure for single-site (or catchment average) continuous rainfall and evaporation modelling (year 2); a national procedure to model spatial variability of daily rainfall and to obtain sub-daily spatial rainfall by disaggregation (year 3); a proven methodology to simulate detailed radar rainfall fields (year 3) with national roll-out in year 5; guidance to users concerning the relative importance of spatial rainfall properties and appropriateness of methods as a function of catchment type and scale (year 2).

Approximate costs £1 million. Negotiation with the UK Met Office will be required concerning raingauge and radar data. This is a generic issue for the DEFRA / Environment Agency R&D Programme requiring policy guidance.

Component 4 National river catchment flood frequency using continuous simulation

Chapters 2 and 3 of this report discussed the role of continuous simulation as the recognized major new approach to river flood frequency estimation because of the hydrological advantages it can offer over event-based approaches. Continuous simulation of catchment runoff time series provides estimates of frequencies of occurrence of floods of particular magnitudes; the flow series can also serve as spatially-distributed inputs to hydrodynamic modelling, and they have the potential to provide catchment hydrological input to next-generation Catchment Flood Management Plans (currently using event-based approaches). Continuous simulation opens up the possibility of increased alignment of water resource (as well as flood management) modelling. It is not, however, a trivial issue to resolve discretisation and parameterization issues.

Component 4 of the BSM Hydrological Strategic Programme therefore addresses the need to exploit advances in hydrological runoff modelling techniques for the advantages they offer design and planning through river flood frequency estimation.

Component 4 will deliver methods for flood frequency estimation by continuous simulation, that is, by catchment modelling of complete flow time series (as opposed to flood events alone). The methods will apply to the whole of Britain, for ungauged as well as gauged locations. The project builds on the successful prototype scheme developed under recent MAFF funding.

The major thrusts of the R&D over the next three to five years are likely to be (i) the use of an enhanced data sample (over that of the prototype) for spatial generalization (or 'regionalization') to ungauged sites in as robust a manner as possible; (ii) the evaluation of alternative approaches to spatial generalization; and (iii) the incorporation and development of pilot work on quantifying the uncertainty associated with flood frequency estimation..

These aspects of research will be followed by review and evaluation to determine levels of further testing and/or development and the appropriate levels of uptake with regard to recommended practice. In the mid-late part of the five to ten year period it will be considered whether a move from implicit towards more explicit handling of catchment behaviour (e.g. snowmelt processes, land management details) is capable of being considered *in the spatially generalized context.*

An indicative cost is estimated at £1.3 million over five years. As with Component 3, data availability issues need to be clarified.

Component 5 Modelling impacts of land use and land management change

A central issue for BSM is the representation of land use and land management, and in particular the impacts of changes. This is a large and complex issue needing scientific research into hydrological processes, methodological modelling developments and applied research to produce practical decision-support tools. There is a need for a co-ordinated national programme of research that links, for example, the applied interests of DEFRA/Environment Agency, the water utilities and English Nature with the more fundamental research interests of the Research Councils. Aspects of rural and urban land use are considered separately below.

Rural land use and soil management

There is a need to review, and define a research agenda for, impacts of rural land use and soil management on flood generation. Information of variable quality is available from both process and modelling studies. A synthesis is required which recognizes, *inter alia*, possible effects of scale. Generic work can be usefully drawn in from beyond UK experience. This study (~ £60k) should include:

- Comprehensive literature review of field, analytical and model sources.
- Comprehensive review of on-going initiatives not yet encapsulated in the literature.
- Identification of key UK data sources on impacts.
- Critical assessment of the overall picture provided by assembled sources.
- Consultation as required for production of the two following reports.
- Report covering individual impact study information in succinct form, the conclusions drawn from this, and the rationale of the derivation of the conclusions.
- Report on recommended research programme for the impacts of rural land management on flooding, including their handling in BSM and in FEH contexts.

No new impact studies will be undertaken at the scoping stage. The subsequent research programme may involve targeted experimental research and will map out an extensive phase of modelling development. New theoretical and empirical modelling research are likely to be required to address the problems of translating improved scientific understanding of land use and management impacts into decision support tools. The wider aspects of land use science and aspects of the theoretical modelling research could be considered appropriate for Research Council support, and are consistent with the scientific objectives of LOCAR and CHASM, for example. This work should draw on a wide range of research inputs. Nevertheless we estimate the costs of a targeted DEFRA/Environment Agency five year research programme to be £1 million.

Urban flooding

A significant proportion of flood insurance losses arise from flooding in the urban environment, commonly associated with runoff which exceeds the capacity of urban storm drainage systems. Two problems occur: a) Most storm drainage is currently designed for frequent (two year) return period events under the criterion of pipe-full flow; there is a variable and generally unknown factor of safety for surface flooding from sewer flows, and therefore a mismatch between standards of risk commonly adopted in fluvial flood design and in urban drainage. b) Although in the past two decades an extensive design capability has been developed for urban storm sewer systems based on event simulation, this does not adequately represent surface flows, which may arise under extreme events. There is therefore a gap in design capability. Added to these problems, there is a legacy of old sewers with variable performance and major concern within the water industry that climate change will increase the incidence of urban flooding. It is therefore necessary to define research priorities for urban response to extreme floods and a research programme to provide a national methodology for assessment of flood risk due to urban flooding. This requires a scoping study which will:

- Review the international state of the art on urban flood design
- Review data availability (including new developments in high resolution, remotely sensed data) to characterize urban land use, surface topographic controls on runoff routing, and storm drainage systems and hence support new developments in simulation capability
- Review design procedures for high temporal resolution rainfall data
- Review data on urban runoff from extreme events
- Produce recommendations for national research programme
- Hold community consultation workshops
- Report recommendations with any revisions in light of consultation.

As in the case of rural land use, this scoping study will be of modest cost (~ £30k) but will define a major national research programme. This will need to focus heavily on the issues of data capture and data assimilation, is likely to draw on developments on remote sensing, and to require pilot field research. We estimate the costs to be at least £1 million for a five year programme. However, it is likely that at least some of these costs lie with a range of interested parties, including EPSRC and the water utilities.

Urban flood response at the catchment scale

For BSM, it is necessary to represent the hydrological response of urban areas at catchment scale, while preserving effects of spatial location. As noted above, current methods can simulate the detail of urban drainage systems, but not for rare events; at catchment scale, current methods represent the aggregated response of urban catchments based on regional unit hydrograph analysis of a limited data-set. There is a methodological gap; new methods are needed to encapsulate knowledge and research in urban flood hydrology into pragmatic and efficient representation at medium-large catchment scale for broad scale modelling in order to explore planning scenarios. It is likely that some form of meta-modelling will be required to capture the essential flood response characteristics. In addition, the representation of urban development in catchment BSM must maintain long-term water balance considerations, and should distinguish any significant differences in urban response relating to urban design, for example the implementation of storage and/or SUDS approaches. As above, a scoping and consultation exercise is proposed to summaries the state of knowledge and define a national research agenda. This will:

- Review key controls of urban flood generation and their current representation at catchment scale.
- Define *generic*, not model-specific, methods for efficient inclusion of urban hydrological response defined, if necessary, by scale groupings.
- Consider checks to ensure short-term agreement of catchment model and urban response, and also of long-term aspects to provide correct pre-storm initial conditions.
- Produce recommendations for implementation and evaluation of generic methods.

A short (~ £30k) study is envisaged, leading to a medium-term research programme. We envisage costs of the order of £400k for a five year programme targeted on the needs of BSM.

Component 6 Climate impact modelling

Impacts of climate variability and climate change on flood risk are of major concern, and an important output from BSM will be quantification of those impacts, whilst fundamental climatic change modeling resides in the REUU Theme. Hence there is a need to provide appropriate inputs to continuous simulation rainfall-runoff models to represent the actual and likely effects of climate change for BSM. These should build on two approaches: a) the interpretation of climate change scenarios for BSM, and b) the quantification of change in observed data:

- the interpretation of climate change scenarios for BSM

  To provide appropriate inputs to rainfall-runoff models to represent the actual and likely effects of climate change, rainfall and potential evaporation properties must be adequately represented. The main issues are that currently available scenarios of change from GCMs are obtained at relatively coarse spatial resolution, and published at relatively coarse time resolution (e.g. monthly). From 2002, resolution for UK scenarios from the Hadley Centre model will be improved to 50 km, with six-hourly extremes available. However, there remains the need to translate these scenarios to the space and time-scales relevant to BSM and to identify the associated model parameters for application of continuous simulation methods.

- the quantification of change in observed data

The main issues are that analysis of rainfall trend is problematic (the detection of change in very noisy signals is difficult), and, as for a), results must be translated into model parameters for continuous simulation. Further research is required to quantify changes in extreme rainfall from historical data, including investigation of alternative approaches, supported by theoretical work on the identifiability of trend. This should include changing occurrence of weather types and intensity-duration-frequency relationships.

These analyses must link to Component 3 to translate changes into parameter values for the rainfall models to be used to support continuous simulation modelling. The programme will need to adapt to change in the technology underpinning the generation of climate change scenarios.

Specific outputs are as follows: year 2, Analysis of trend in UK rainfall data, disaggregation of GCM/RCM outputs to BSM scales of interest, parameter guidance for single-site rainfall and evaporation models; year 3 parameter guidance for simplified spatial-temporal rainfall models; year 5 parameter guidance for full spatial-temporal rainfall models.

Approximate costs £300k for a five year programme.

Component 7 Building a new modelling capability

Chapter 3 above has highlighted the limitations of current practice. To meet the needs of BSM, major methodological developments in modelling capability are clearly required. However, this raises a complex set of interdependent issues. It is clear from the review that models cannot be viewed in isolation from data support; increasingly models are seen as a vehicle for data assimilation, and hence model development is intimately linked to issues of the availability of conventional and new data sources. It is also evident that issues of scale in the representation of hydrological processes are fundamental to linking representation of land use change with catchment scale modelling; new data sets are required to investigate these issues. At the same time, model development must be consistent with the framework of decision support application, and increasing computer power is enabling new modelling developments and new approaches to the representation of uncertainty, which can provide the user with the capability for more informed judgement of the impact of management strategies.

Component 7 therefore focuses on three key work packages, but these must be set within a closely integrated programme.

7a Generic modelling techniques

All components of the BSM HSP, whether tool building or application, are to some degree dependent on the techniques of modelling, that is, the building-blocks of methodologies.

Plainly, in a number of respects these modelling techniques are sufficiently advanced to be able to offer useful output in addressing flood management issues: examples of this include the recent advances in national systems for rainfall and runoff continuous simulation (Components 3 and 4).

The fact that such modelling systems are available rests on research into model techniques over a number of years. For continued improvements over the medium to long term, the development of sophisticated generic modelling techniques is to be supported, with the benefits feeding into new generations of modelling tools. This type of research is in all cases associated with the more ‘pure’ science funding routes, but past experience has also shown that it is also the specific practical flood management issue which has targeted attention on a solution.

Below are major generic modelling challenges:

- efficient levels of incorporation of process detail within model systems
- model calibration techniques
- interchangeability of scales within and between models; temporal and spatial down/upscaling; nesting of scaled models
- quantitative expression of uncertainties associated with parameterization, with data, with model structure; combination thereof
- overall risk-based and combined probabilistic modelling approaches.

Components 3, 4, 5 and 6 do not, of course, operate without the recognition and handling of these issues and, indeed, they feed back experience and application to Component 7. It is appreciated also that some relevant technique development is likely to be provided by the REUU Theme. Benefits will also feed into the FFW Theme. Funding requirement is significant but is likely to be shared between themes and to benefit from research commissioned outside DEFRA / Environment Agency. An approximate budget figure is £0.8 million over five years.

Component 7a serves to pool experience and extend techniques of benefit across the range of model investigations and, indeed, can assist in BSM beyond their main hydrological remit.

7b Data and data assimilation

Two main themes emerge from the review of BSM: a) rapid changes in technology will have far-reaching effects on our capability for environmental simulation in terms of computational systems, data availability and the role of data assimilation, and b) there are difficult methodological problems to be resolved in the development of a Broad Scale Modelling capability, in particular with respect to the linkage between model parameters and catchment physical characteristics, and hence, for example, prediction of effects of land use change. There is therefore an opportunity to build on the new developments to address these methodological issues.

Hitherto, modelling exercises in practice necessarily have had to adapt their approach to the data available. However, for significant progress to be made, the value of new sources of data and new approaches to data provision must be explored in the context of developments in data assimilation. Research is therefore needed, and, based on the results, a dialogue must be developed between modelling R&D and data providers.

Recall that the major emphasis of flood management data issues resides in the REUU Theme: Component 7b is introduced to ensure BSM data requirements are anticipated, met and supported.

This component therefore seeks:

- to investigate the use of new data sources in model conditioning, including spatial data-bases and both hard and soft local data
- to support the development of new experimental data-bases to underpin the above (e.g. building on the National Infrastructure for Catchment Hydrology Experiments (NICHE) which comprises the LOCAR and CHASM initiatives)
- to develop appropriate methods of data assimilation (representing the associated uncertainty as appropriate)
- to link with Component 7a in addressing methodological modelling issues which include the linkage between model parameters and physical catchment properties, the scale-dependence of model parameters, the use of new data sources, the role of both hard and soft data in conditioning simulations
- to establish a dialogue between data providers and model developers to define the associated national and local data needs, together with issues of access, quality control and format.

The issue of data and data assimilation is seen as a fundamental requirement of the BSM R&D programme, budgeted at approximately £1 million over five years. It is indicated as a component separate from an IT framework, though intimately associated with it.

7c IT framework

As noted above, rapid developments in computing systems are taking place, not only in computing power, but also in the architecture of computing systems. This has had a major impact on simulation methodologies: stochastic analysis of models and the explicit treatment of uncertainty are now being applied to hydrological and flood inundation modelling. It will also have a major impact on data assimilation methods, and the access to existing and new data sources. The role of data can be seen as conditioning model simulations, and minimizing uncertainty in parameters and predictions. These developments should be incorporated in the vision of a future (five year) open-architecture BSM modelling and decision support system, preferably with open source code, consistent with the needs to link with socio-economic and environmental aspects of the planning and management of flood protection, and be available in the public domain. It is estimated that a programme of the order of £0.8 million over five years will be required.

Scoping study for Component 7

The design of Component 7 is challenging, and requires high level input from leaders of the UK research community, preferably with international inputs. A scoping study is proposed, based on an expert panel and consultation exercise, to define an integrated programme of work across these three areas.

A vision is required for a computational and data-support framework for broad-scale modelling to maximize the benefits of advances in computing systems, data availability and data assimilation methods. The framework should be designed to accommodate tidal and estuarine river reaches, in addition to non-tidal, and the project is likely to build on MAFF’s 1997 ‘Whole Catchment Modelling’ scoping study, the BSM ecosystem scoping of FD2108, and development of the Modelling Decision Support Framework (MDSF) project W5F(01)01.

The principal elements of the programmes of generic modelling development and data and data assimilation are indicated above. Careful thought must be given to the development and management of an integrated programme; effective feedbacks between the three elements are essential to the overall objectives.

This scoping study should:

- Convene expert working group
- Review developments in computing systems
- Review generic developments in hydrological modelling
- Review developments in data availability and access (including new data sources)
- Review developments in data assimilation and uncertainty estimation
- Produce five year vision
- Hold workshops / consultations
- Produce final vision and costed work programme.

Approximate scoping costs £60k, six-month time-scale. (A draft specification is included in Appendix 1.) The output will be recommendations for a research programme with costs and time-scales to achieve the vision of a next-generation BSM framework.

Component 8 Software production

Output of HSP Components 3 to 7 described above are quantitative knowledge and solutions to the range of hydrological flood management concerns. The techniques developed and employed are at the 'research code' level. Component 8 addresses, therefore, the issue of the production of software products for users who solve flood management problems but do not themselves develop techniques.

The question of domain of tools and how integrated they should be is likely to be largely defined by Component 7, beginning with the scoping component. Component 8 focuses on detailed specification, design and software development. The research element of this component is not particularly costly, but providing a fully-tested software tool set for national methodology will be expensive with costs depending on commercial considerations: an estimated figure of £1.2 million is included for the five year programme.

Limiting Factors

The delivery of BSM requires that an integrated and multi-faceted programme of research is undertaken. The most important potential limitation is insufficient support to address all of the above aspects; all must be addressed if the aims of BSM are to be achieved. A second limitation concerns programme management. It is essential that a vision of an integrated programme is carried forward and implemented in project management if the elements of research are to combine as needed for the final delivery of the BSM tool. It is to be noted that it is always the case that results of research are not completely predictable: what can be guaranteed is that appropriate directions are explored in a professionally competent manner.

Further limiting factors relate to data. Access to a wide range of data holdings is essential, including spatial precipitation, evaporation, observed flows, topography and land use, as well as the exploration of new data sources described in Component 7b. Agreements for data access to the research community to develop the tools will be essential, and ultimately the licensing of data products to the user community.

Full delivery of benefits requires maintenance of a proper skills base in terms of research expertise and of ability to promote dissemination and uptake of research outputs by flood managers. This point is also identified by the Institution of Civil Engineers (2001)

Summary of the vision

Given the programme as defined above, the expected deliverables and their timetable can be summarized as follows:

The following are considered achievable within a three year horizon:

i) Improved (simplified) methods for spatial rainfall inputs to large catchment broad-scale modelling

ii) Improved methods to disaggregate scenarios of climate change

iii) Regionalization methods for parameter-sparse hydrological models for ungauged catchments/sub-catchments for broad-scale flood frequency estimation

iv) Investigation of appropriate methods of representing in-channel structural controls and out-of-bank flows in broad-scale models

v) Development of a flexible tool–kit for broad-scale modelling, including state-of-the-art parameter identification and uncertainty analysis routines, and using an open architecture to allow development and extension. On this three year time-scale, this would mainly be based on currently existing modelling components.

The following are considered achievable within a five year horizon:

vi) Improved scientific understanding of the effects of land use change and their representation for broad-scale modelling

vii) Improved understanding of climate variability and improved resolution of scenarios of climate change

viii) Improved spatial-temporal rainfall modelling (continuous space and time) as inputs to broad-scale models (on this time-scale radar archives will enable much more substantive analysis)

ix) New techniques, such as meta-modelling, to combine the complexity of aspects of process modelling of catchment change with the computational requirements of broad-scale decision support systems

x) Improved hydroinformatic systems to assimilate local and regional data, including information on in-channel flows and their structural controls, remotely sensed flood plain data for out-of-bank hydraulic modelling, and remotely sensed land-use data

xi) Evaluation of new data sources, and their role in improved model conditioning

xii) Improved representation of the urban environment in BSM

xiii) Improved methods of ecological modelling for BSM

xiv) Pilot applications of the broad-scale modelling methodology.

The following are considered achievable within a five to ten year time scale:

xv) National roll-out of the BSM method, following comparative evaluation with existing practice, with the necessary focus on dissemination

xvi) Progressive development of the underpinning science and modelling tools

xvii) Periodic review and reevaluation of strategic approaches.

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