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

Research and Development

# Final Project Report

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| Project title | Catchment Management System<br>Phase 1: Framework and Demonstration |
| DEFRA project code | **FD0421** |
| Contractor organisation and location | CEH Wallingford<br>Wallingford |
| Total DEFRA project costs | £ 433475 |
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| Project end date | 31/03/02 |

## Executive summary (maximum 2 sides A4)

The objective of the MAFF Project "Catchment Management System. Phase 1: Framework and Demonstration" is to build a prototype Catchment Management System for the purpose of catchment management planning, with special reference to flood defence issues. In particular, the system will provide a direct linkage between hydrological and hydraulic models in order to provide an improved tool for the assessment of flood risk within a catchment. The system will enable a wider range of practical problems to be addressed than at present. It will allow catchment management practices, environmental (including climate) change together with land use and planning scenarios to be explicitly included in future flood risk assessments.

The Phase 1 study aims to provide a framework program together with demonstration applications. These will serve to illustrate to practitioners the form of catchment management system envisaged and the need for support of its continued strategic development. It is intended to provide a system which will be easy to use and afford practical answers meeting user needs. The design of the framework will allow for the incorporation of any set of models in any configuration, with the possibility of interaction between models. Existing models will be used for demonstration in order to focus effort on development of the generic model framework.

Whilst flood defence applications will feature predominantly in the demonstration system, the design will be such as to allow a wide range of water management issues to be addressed, extending from flood defence to environmental (water quality, ecology) management and economic aspects of these. The relevance to the production of Local Environment Agency Plans will be demonstrated.

The Final Report "Catchment Management System. Phase 1: Framework and Demonstration", published as a separate document (CEH Wallingford and HR Wallingford, 2002), records the main outputs and achievements of the project. It is made up of four distinct parts complemented by an Executive Summary. Part 1, entitled "Whole catchment modelling: progress and prospects", serves to provide an overview of the project achievements. It was published as the report to the 35th MAFF Conference of River and Coastal Engineers held at Keele University in July 2000. Part 2 comprises the Powerpoint Presentation produced for the conference, and contains important illustrative material as well as providing a concise overview. Part 3 entitled “Framework for Whole Catchment Modelling. Interim Report.” is the Interim Report to the Project developed in the first year of the study. This contains important review material supporting the design of the framework program and the demonstrator case studies, together with an outline work programme for subsequent years. Further details of the demonstrator case study of Milton Keynes, a new town development provided with flood detention lakes, is contained in a separate contract report to MAFF: “Whole Catchment Modelling – The Milton Keynes Case Study. HR Wallingford Progress Report. Report TR 77, January 1999”.

Part 4 entitled “System Design: Specification of Data Structures which define a modelling problem.” is the main technical output of the project and provides an incomplete draft specification of the data structures required to support the detailed coding of the framework. The detailed coding of the framework progressed significantly in prototype form. However, the complexity of the design arising from the requirements identified from the Scoping Study proved onerous to implement as code. This led to the final abandonment of the code development before a workable demonstrator framework was realised. The Final Report serves as a statement of the achievements of the project and contains material that may serve to guide a future development of a Catchment Management System.

## Scientific report (maximum 20 sides A4)

**Projective Objectives**

The objective of the MAFF Project "Catchment Management System. Phase 1: Framework and Demonstration" is to build a prototype Catchment Management System for the purpose of catchment management planning, with special reference to flood defence issues. In particular, the system will provide a direct linkage between hydrological and hydraulic models in order to provide an improved tool for the assessment of flood risk within a catchment. The system will enable a wider range of practical problems to be addressed than at present. It will allow catchment management practices, environmental (including climate) change together with land use and planning scenarios to be explicitly included in future flood risk assessments.

The Phase 1 study aims to provide a framework program together with demonstration applications. These will serve to illustrate to practitioners the form of catchment management system envisaged and the need for support of its continued strategic development. It is intended to provide a system which will be easy to use and afford practical answers meeting user needs. The design of the framework will allow for the incorporation of any set of models in any configuration, with the possibility of interaction between models. Existing models will be used for demonstration in order to focus effort on development of the generic model framework.

Whilst flood defence applications will feature predominantly in the demonstration system, the design will be such as to allow a wide range of water management issues to be addressed, extending from flood defence to environmental (water quality, ecology) management and economic aspects of these. The relevance to the production of Local Environment Agency Plans will be demonstrated.

**Project Achievements**

The main outputs of the Project are contained in the Final Report published as a separate document (CEH Wallingford & HR Wallingford, 2002). This Final Report is made up of four distinct parts complemented by an Executive Summary. Part 1, entitled "Whole catchment modelling: progress and prospects", serves to provide an overview of the project achievements. It was published as the report to the 35$^{th}$ MAFF Conference of River and Coastal Engineers held at Keele University in July 2000. This overview forms the basis of the Scientific Report presented here in subsequent sections, in amended and updated form. Part 2 of the Final Report comprises the Powerpoint Presentation presented at the conference, and contains important illustrative material as well as providing a concise overview. Part 3 entitled "Framework for Whole Catchment Modelling. Interim Report." is the Interim Report to the Project developed in the first year of the study. This contains important review material supporting the design of the framework program and the demonstrator case studies, together with an outline work programme for subsequent years. Further details of the demonstrator case study of Milton Keynes, a new town development provided with flood detention lakes, is contained in a separate contract report to MAFF: "Whole Catchment Modelling – The Milton Keynes Case Study. HR Wallingford Progress Report. Report TR 77, January 1999". Part 4 entitled "System Design: Specification of Data Structures which define a modelling problem." is the main technical output of the project and provides an incomplete draft specification of the data structures required to support the detailed coding of the framework. The detailed coding of the framework progressed significantly in prototype form. However, the complexity of the design arising from the requirements identified from the Scoping Study proved onerous to implement as code. This led to the final abandonment of the code development before a workable demonstrator framework was realised. The Final Report serves as a statement of the achievements of the project and contains material that may serve to guide a future development of a Catchment Management System.

**Scientific Overview**

Until recently, it has been necessary to limit the scope of investigations when considering the impact of various development proposals which affect the natural water environment. This stemmed from a lack availability of tools designed to allow a more general and more widely ranging investigation of a development. Such an investigation would be able to model the development's effects not just locally, but over the full extent of a natural catchment or over water-supply systems encompassing several catchments. The types of development involved could include not only physical developments in terms of flood relief works or new towns but also water-resource developments affecting the abstraction, storage and discharge of water. Catchment-wide impacts arising from changes of land use or climate might also require investigation. Consideration could extend beyond water quantity to encompass water quality, ecological, economic and sociological impacts. The fundamental requirement is for a modelling tool which can:

(a) represent the full range of physical processes involved in water movement within a catchment (hydrological, hydrodynamic and groundwater processes) ;
(b) treat the problem in appropriate detail, with perhaps more detail in the immediate vicinity of a proposed development;
(c) be capable of modelling water-flows throughout the whole of a catchment including water-supply storages.

The above requirements for wide-ranging investigations have lead to the idea of "integrated catchment management" or "whole catchment modelling" in which relatively simple modelling components are combined together so as to provide a decision support tool for catchment management. Here each separate component would represent a distinct part of the water-cycle (e.g. a rainfall-runoff model or a channel-flow routing model) over a reasonably limited geographical scope.

This Scientific Report describes the steps taken under the Catchment Management System project to construct a framework program with the inherent flexibility to be able to join and execute together a practically unlimited set of modelling components. This flexibility is achieved by adopting a generic approach to the set of modelling tasks to be included, while the desirable traits of fast and easy execution are also accommodated. A main aim is to design a framework so that new modelling components can be easily added and so that it can be readily implemented when new catchments are modelled. The Scientific Report also includes as an example a discussion of how such a framework program might have been applied to a specific design problem. In particular, the report describes the potential use of a combined set of hydrological and hydrodynamic models as part of procedures to size and to develop operating rules for flood-detention lagoons as part of an urban development, taking the town of Milton Keynes as the case study.

## 1. Introduction

The potential usefulness of a "Whole Catchment Modelling" or "Catchment Management" system has been presented in the Scoping Study Report by Naden et al. (1997). This report summarised the results of a consultation process reviewing what such a system might be expected to do for the UK Government, the Environment Agency, Water Services plcs and Local Authorities. It involved considering the interests of users having a wide range of functions, including flood defence, water resources and water quality. The scooping report took the view that a Whole Catchment Modelling System would "enhance the coordination between policy objectives, management planning, operational practice and their underpinning through existing science and future research".

It will be clear from the above that the Scoping Study Report identified many requirements that a Whole Catchment Modelling System might serve. Whilst not all requirements would be needed for particular types of application, given so much overlap in requirements it would be desirable to encompass all of them within a principle of “one framework, many models”. A particular application would be undertaken by first selecting a number of models to construct the datasets required for a given problem, and then building these models into a standard framework. The framework would pass datasets between the various models, control their order of execution and store, display and report on the results

The project described in this Scientific Report has been concerned with setting-up such a framework as was envisaged within the Scoping Study Report. The initial target has been termed a “demonstration system”, with the aim that this will be used initially on rather simple examples of what could be done with a fully-fledged system. It was not envisaged that the demonstration system would necessarily be taken on to a full development version, since it may be more appropriate to leave the construction of such software to commercial interests. However, it was a clear intention that the construction of the demonstration system should be used as catalyst to the design of appropriate data-structures necessary to allow a Whole Catchment Modelling System to fulfill the range of requirements identified in the Scoping Study Report, as well as to cover the range of applications envisaged therein. In fact this could be considered to be the primary outcome of this project. In order to achieve this important goal it has been necessary to construct the demonstration system in such a way as to cover the whole of these ranges of requirements and applications in at least a notional form so as to provide a reasonable test for the question of whether the proposed data-structures would allow a Whole Catchment Modelling System to work as intended. This clearly goes a long way beyond the rather simpler task of constructing a program to use the limited number of models and tasks associated with the problems to which the demonstration system might be applied.

Work within the project on designing the demonstration system has based some of the ideas and the general approach used on experience at CEH Wallingford (formerly the Institute of Hydrology) with the Information Control Algorithm (ICA) used within the River Flow Forecasting System that has been employed operationally within some regions of the Environment Agency and SEPA for nearly a decade (Moore and Jones, 1991; Moore *et al*., 1994; Moore, 1999). The ICA and its data-structures share some of the capabilities required of the target system. These include control of execution and data-passing within a network of models, and allowance for the inclusion of new models via a generic model interface. However, the overall requirements of the Whole Catchment Modelling System concept are so much more vastly extensive than those for the relatively simple task of real-time flow forecasting that it was felt best to start the design *ab initio*. One can then hope that the design will take a balanced view of the overall set of requirements, rather than be contorted by growing out of a design specifically adapted to a much narrower context.

In this Scientific Report, Section 2 outlines some of the major design requirements and abilities that have been identified as necessary for the Whole Catchment Modelling System. While we would hope to be able to cover all of the requirements identified in the Scoping Study Report, we have chosen to emphasize those which have had most influence on the development of the demonstration system. Some other general requirements have been mentioned previously in the Scientific Overview to this report. Section 3 outlines some parallel work that has been undertaken into setting-up a simple but realistic problem that will be used as a target application for the demonstration system.

## 2. Design Requirements for a Whole Catchment Modelling System

Much of the discussion in the Scoping Study Report concerns the range of models that might be of use within a Whole Catchment Modelling System. This is a very extensive list of potential model types. For the purposes here, it is sufficient to note that this includes the obvious categories of water-related models (hydrological, hydrodynamic, groundwater, wetland and floodplain models) but, in addition, other categories of models capable of dealing with in-stream chemistry, in-stream biology and sediment. Models for water-supply systems and for water in the urban environment would also be possibilities. It was certainly envisaged that a Whole Catchment Modelling System might well need to be able to deal with problems involving tidal rivers and estuaries. Further, the system would need the capability of carrying out (which is another way of saying that it would need a “model” for) risk-based assessments, including environmental impact and economic criteria.

*Multi-model requirement*

While the Scoping Study Report tried to categorise the possible types of model under sets of headings similar to those above, this notion is irrelevant to the design of the system at the low level being considered here. It would, of course, be a prime consideration if one were trying to devise a GUI or other tool for model configuration which might well feature menus of models categorised under such headings. However, communication (data-transfer) would be needed between models both in the same and in different categories. Therefore, at the lowest level and in the simplest terms, the framework simply needs to be able to provide a mechanism for passing data between models of any types. This has the advantage that the design of the framework does not have to provide one set of special considerations for rainfall-runoff models, another for hydrodynamic models, another for groundwater models, and so forth. It has the further advantage that a substantial degree of generality is built into the design from the start, since it implicitly avoids the danger of designing the system to meet the needs of only one specific rainfall-runoff model, one specific hydrodynamic model, etc..

*Multi-resolution and multi-dimension requirements*

The design of the system needs to take account of the different types of data handled by different types of models. Many of these datasets will be of a time-series nature, but the resolution at which values are held may well differ between models. For example, 15-minute time-steps may be appropriate for rainfall-runoff models on small catchments and for hydrodynamics models, while a daily time-step may be best for a model for a large aquifer. Certain datasets may not be of a time-series nature: for example, the output from models undertaking risk assessment may be a rather small set of numbers representing a whole time-period. Datasets may also have a spatial aspect to what they represent: values at a single geographical point, on a line, on a grid or in 3-dimension space. All these are aspects of “resolution” and “dimension”. Different models will require inputs and outputs at different resolutions and different dimensions. While certain existing models may already contain interfaces which would allow for some choice between a number of different options in regard to resolution and dimension of inputs and outputs, it would be wrong to design a system which would rely on each model providing its own facilities. This would mean that such facilities would need to be incorporated into any new model before it could be built into the Whole Catchment Modelling System. The idea is to build a framework in which the inclusion of new models is made as easy as possible. It is therefore appropriate that the tasks of changing- resolution and changing-dimension should be handled within the framework linking the models, since such facilities will then be available for all models. It is clear that the question of changing the units of measurement in which data may be required by different existing models can be treated as a simple extension of the same idea.

*Multi-looped requirement*

The Scoping Study Report identifies the need to be able to deal with models which interact with each other, reflecting the fact that the notionally-different elements of the water cycle (hillslopes, river channels, groundwater, etc. ) do interact with each other. A basic concept of the approach to Whole Catchment Modelling suggested by the Scoping Study Report is that it should be made of separate models reflecting the different elements. This is partly so that a user may be given a choice of what models to use for a given element, but more importantly to provide control over the detail with which particular aspects of a problem are treated taking into account the relative importance of variations arising from different elements of the water cycle and from different parts of a catchment. The separate-models approach may be contrasted with one in which there is a single monolithic model-structure. With the latter, interaction between different elements of the water cycle could be handled directly within the mathematics of the overall model. However, there would be no choice of how each element of the cycle is handled, since the model would be an all-or-nothing entity. With the separate-model approach selected here, the design for the framework is faced initially with the task of identifying sets of models within a network of models which form loops within a network of models. The design then needs to provide for the control of execution of the models in such loops in order that a satisfactory solution to the problem can be found. In order to provide sufficient generality, the framework needs to be able to deal with not only simple loops but with multiple sets of inter-linked loops of models. However, the framework needs to provide for the efficient execution of models in networks which do contain such multiple loops: it would be inappropriate to adopt an iterative procedure executing all models at every iteration when only the models in loops require iterative execution.

*Multi-layered requirement*

Specifying the tasks that might need to be done with the framework relates not just to the different models to be included, but also to other aspects of how a study might be performed. For certain studies, such as flood frequency analyses via continuous simulation, model runs may refer to rather lengthy time-periods of perhaps a thousand years, or they might consist of multiple simulations over rather shorter time-periods, perhaps 20 years corresponding to the concept of a planning period. Other applications might be treated by using a selected historical time-period, or several selected historical events, in order to study how changes to flood defences, or to land-use, might affect model-outcomes. As well as providing for such possibilities, the design of the framework has introduced the idea of multiple-layering of the network of models. The idea here is to provide for the situation where particular types of model are computationally expensive to run, but where the results are only really needed during exceptional events. For example, simple flow-routing procedures may adequately treat a junction of two rivers most of the time, but it might be best to use a hydrodynamic model to deal with backwater effects during periods of really high flow. The multiple-layering feature would allow simple models to be run over a continuous time-period for an initial layer of models, and the results from these could be used to automatically select short time-periods over which to execute models in a second layer. The multiple-layering feature could be useful in several other ways. For example, it could be used to split-up the model-run for an overall problem into a number of stages, so that an investigator can examine the results from a given stage before proceeding to the next.

To summarise, the design for the framework is intended to provide for a Whole Catchment Modelling System which will be multi-model, multi-resolution, multi-dimensional, multi-looped and multi-layered.

## 3. A case-study application at Milton Keynes

### 3.1 Introduction

The present project to develop a demonstration system for Whole Catchment Modelling has involved some parallel work in putting together a realistic “case study” for use in the demonstration. For this purpose, it was felt useful to find a problem which had already been solved by traditional methods in order to provide a contrast between these methods and what might be possible using a Catchment Management System. The case study chosen was one concerning the design of flood detention lagoons at Milton Keynes. The present section describes some aspects of the work involved in setting up and calibrating the hydrodynamic model required for the Whole Catchment Modelling System. Within the eventual demonstration system, this model would be complemented by others, such as rainfall-runoff models, which would be used to construct flow-inputs to the hydrodynamic model. Such rainfall-runoff models, which are not described here, are distinct from the “hydrological modelling” applied in the more traditional approach to scheme evaluation.

The issue to be addressed within the Milton Keynes Case Study was defined during early stages of the work as:

"*an assessment of the impact of the Milton Keynes ('new-town') development, including storage reservoirs, on flood levels in the Milton Keynes area*".

This development, which was constructed on land which had previously been liable to frequent flooding, included a number of storage reservoirs to compensate for the proposed loss of flood plain storage. Willen, Caldecotte and Tongwell Lakes are off-line storage reservoirs, with Furzton, Loughton, Linford and Cosgrove Lakes providing on-line storage.

Milton Keynes was the chosen location for the demonstration part of the study because of the clarity of the distinction between pre- and post-development situations and because of the extensive construction of flood storage reservoirs as part of the development process. There were also thought to be comprehensive hydrometric and topographic datasets available for both scenarios, which could be used for effective calibration. These datasets subsequently proved a limitation to the extent of the study. The development area is situated within the Upper River Great Ouse catchment and covers approximately 90 $km^2$ – equivalent to over 10 % of the total catchment area to Newport Pagnell (800 $km^2$). Development began in 1969 and was substantially complete by the end of the next decade.

### 3.2 Description of work

The Ouse catchment and tributaries lying within the project area have been modelled using existing hydraulic and hydrological "design-event" modelling techniques. The hydraulic model of the River Ouse extends from its confluence with the River Tove to a point just beyond the confluence with the Ouzel at Newport Pagnell. The River Ouzel was included in the hydraulic model with the upstream limit being at Caldecotte Lake. Loughton Brook was also modelled with the upper limit being the point at which the Tear Drop Lakes discharge beneath the A5 trunk road. The initial work for the case-study comprised the following elements:

(i) "Design-event" modelling of both the complete Ouse catchment to Newport Pagnell and also the individual catchments providing inflows to the upper reaches of the hydrodynamic model;
(ii) Hydraulic modelling of the existing situation i.e. after the development of Milton Keynes and all existing flood detention reservoirs;
(iii) Hydraulic modelling of the pre-1970 situation i.e. prior to any development of the Milton Keynes area.

In addition, rainfall-runoff models, based on the PDM or Probability Distributed Model (Moore, 1999), have been calibrated to the sub-catchments for later use in the demonstration system.

### 3.3 Design-event modelling of the Ouse catchment

The inflow hydrographs to the hydrodynamic model were produced using Flood Studies Report (FSR) methodology. This was used because of its general applicability to a wide range of catchment characteristics and its widespread adoption as a standard estimating procedure. The MicroFSR software was used to calculate both the design flood event and actual storm flood event hydrographs, using the physical catchment characteristics and observed and statistically-derived rainfall data. Sub-catchments treated in this way included large rural sub-catchments together with small urban and rural sub-catchments, which provide lateral inflows into Loughton Brook and into downstream reaches of the main watercourses.

To enable the model performance to be checked against observed data, rainfall data and hydrographs for actual storm events were required. The chosen reference storms were 12 July 1968 (pre-development), 15 December 1979 and 24 September 1992 (post-development) – each of which represent significant flood events in the history of the catchment. In addition, an in-bank event, which occurred on 23 December 1998, was selected at a later stage in the project in order that a short length of hydrometric data available for the Upper Ouse could be used as a further calibration tool.

Increasing levels of urbanisation within a catchment increase the rapidity of the catchment's response to rainfall and also enhance the proportion of runoff which occurs. This is demonstrated when the 50-year design-event rainfall profiles and unit hydrographs (UHs) are compared for the catchment to Newport Pagnell, with the resultant change in downstream flow also presented. There is a significant increase in the slope of both the rising and falling limbs of the UHs post-urbanisation, and also an increase in the peak for this case. These changes are directly reflected in the computed design hydrographs.

The 50-year storm used in the study for comparative purposes is that calculated by FSR for the complete catchment to Newport Pagnell. Without a study of historic areal rainfall distributions and storm totals, it is not possible to know whether a storm of such broad coverage is realistic. More intense localised storms of much shorter duration are likely to be critical at many tributary locations, causing higher water levels and localised flooding.

The potential difference in catchment response between the 1 in 50 year design and the observed event storms used for model calibration has been evaluated. The design storm has a significantly greater total storm volume and duration than any of the observed events and therefore for the post-development situation will test the new town's flood defences to a greater degree than has yet been experienced.

Although URBAN (the % of urban area parameter incorporated within the FSR approach) is an important variable in predicting runoff from areas with significant levels of urbanisation, such as Milton Keynes, it is unrealistic to expect its effect to be the same from one catchment to another. Such a coarse treatment cannot hope to model the complexities of different drainage systems.

## 3.4 Hydraulic modelling of the existing situation

*Modelling approach*

The hydraulic modelling of the major watercourses adjacent to the Milton Keynes development was carried out using the ISIS hydrodynamic modelling software. Models of the Rivers Ouse, Ouzel and Loughton Brook were constructed for the current, 'developed' situation, linked together, and run for the 1979, 1992, and 1998 (post-development) floods. Modelled flow and level hydrographs were compared with observed datasets at Newport Pagnell gauging station in order that some calibration of the model could be achieved.

*Data Limitations*

The topographic data included in the model were generally of poor quality and the modelled volumes of floodplain storage are unlikely to be accurate over the full range of modelled levels. Significant effort in site survey and searches of design drawings would be necessary to remedy these shortcomings.

The Environment Agency holds a large number of drawings (cross-sections, long-sections and plans) for the rivers of interest. Due to the high level of usage of the drawings for the Rivers Ouse and Ouzel, they are not all easily accessible for reference. This, combined with the sheer volume of drawings, made it difficult to obtain all the cross-sections and structure details required for the modelling in the time available. Pre-development cross-sections were scarce and where information was available, it was difficult to match the locations of sections to channels where major diversions have taken place. This must be taken as a typical situation which would confront any user attempting a similar impact assessment or flood design problem anywhere in the country. Other model data which were available contained limited information regarding structures and those which were available were not easy to interpret and extremely difficult to transfer to the ISIS model.

Data for the structures on Loughton Brook could not be obtained and dimensions of culverts, etc. had to be scaled from photographs. Anglian Water supplied some information about the Teardrop lakes on Loughton Brook but the data available for the rest of the watercourse were restricted to channel sections.

Because of the absence of site-specific data, the reservoir area-elevation curves for off-line and on-line storages adjacent to the Ouse and the Ouzel were crudely estimated from OS 1:25,000 mapping.

*Model Calibration*

The only gauge site within the modelled reaches is at Newport Pagnell, which lies on the main Ouse, just upstream of the confluence with the Ouzel. No information is available from Anglian Water as to how the Ouzel reservoirs were operated during the events, although operating rules do exist, and their use had to be assumed.

The 1998 event was selected at a later stage in the project in order that the modelled hydrology of the upper Ouse catchment could be assessed at Thornborough. A comparison of modelled and observed data showed a good representation in terms of hydrograph peak and volume. As the 1998 hydrological calibration at Thornborough showed a 5-6 hour delay, the modelled hydrograph was shifted by this amount when compared with the observed data. The subsequent comparison of observed and modelled data at Newport Pagnell also gave a good result. It should be noted that this event not only has validated upstream hydrology but is also an *in-bank*, low order event and therefore, although the results give confidence in the performance of the channel hydraulics, the significant uncertainties associated with flood modelling are avoided.

When observed and modelled data were initially compared for the out-of-bank flood events of 1979 and 1992, it was evident that the model was significantly under-predicting the attenuation in the system. As observed data were only available at Newport Pagnell, and a relatively low level of confidence could be placed in topographic data, no clear conclusion could be drawn as to where the additional flood storage should be accommodated. Site visits indicated that significant floodplain storage is likely to exist upstream of the hydrological model inflow locations. These additional storages could have a large influence on the inflow hydrograph to the model; however, without extensive further topographic survey data, an accurate estimate of the storage could not be calculated.

Therefore, two floodplain storages were included within the model, one adjacent to each bank of the uppermost model reach. The storage and spill levels were varied to achieve a reasonable calibration for the three events. The weir drowning factor at the gauge station also had to be changed from 0.75 to 0.9 in order that both flow and level hydrographs were represented more accurately over the full hydrograph range. It was not considered appropriate to attempt further calibration when such significant uncertainty in model inputs were known to exist.

## 4. Conclusion

This report has outlined some of the design considerations which have been taken into account in the development of what was intended to be a demonstration version of a Whole Catchment Modelling System. A case-study based on the storage ponds at Milton Keynes has been developed for use with the demonstration system. While a single case study cannot exercise the full potential capabilities of a Catchment Management System it is a reasonably realistic one. It certainly demonstrates the difficulty of decision-making when faced with the typical paucity of data that exists in practice.

The Milton Keynes case study aims at demonstrating the capability of an integrated Catchment Management System to address the issue of incremental loss of flood plain and flood control resulting from urban growth. The issue of land use change, including the use of storage reservoirs to mitigate loss of flood plain storage, is especially relevant when the projected need for new housing is considered. A demand for 4.4 million new dwellings over the next 20 years is forecast by Government.

The development of a framework program for Whole Catchment Modelling has extended from the design considerations reported here to an incomplete draft specification of the data structures required to support the detailed coding of the modelling framework (Jones, 1999). Whilst the detailed coding of the framework progressed significantly in prototype form, the complexity of the design arising from the requirements identified from the Scoping Study proved onerous to implement as code. This led to the final abandonment of the code development before a workable demonstrator framework was realised. This report, and the Final Report of the project (CEH Wallingford & HR Wallingford, 2002), serve as statements of the achievements of the project and contain material that may serve to guide a future development of a Catchment Management System.

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## ANNEX

### EUROTAS Hydrological Modelling Component

Whilst the main aim of the Catchment Management System Phase 1 work was the development and demonstration of a prototype modelling framework, the project also provided support under the EU EUROTAS (European River Flood Occurrence and Total Risk Assessment System) project carried out between 1998 and 2000 Crooks *et al.*, 2000). The relation of EUROTAS to the Catchment Management System is discussed in the Interim Report (Moore *et al.*, 1998), also included in the Final Report (CEH Wallingford & HR Wallingford, 2002).

The Thames catchment was used as one of five study catchments in the EUROTAS development and testing of an integrated modelling system for the assessment and management of flood risk. A semi-distributed continuous simulation model, called CLASSIC (Crooks *et al.*, 1996), applied on a grid square (10 km) framework allowed direct incorporation of GIS databases within the set-up and calibration of the model. The model formulation was developed to be suitable for simulation of whole catchment and sub-catchment river flows, and to incorporate the impacts of climate and land use change on these flows and flood peaks in particular. Good results were obtained in simulating daily flows over the full flow range and across the Thames basin, including the lowest gauging station at Kingston (circa 10000 $km^2$) and 12 main tributary catchments.

An extension of this work (Crooks, 2002) considered the applicability of the model to an area other than the lowland Thames basin, with the Ouse basin above Skelton (upstream of York) in Northern England being chosen. Results for the Thames were also extended in time to encompass the high rainfall experienced over the 2000/01 winter. Used as a continuous simulation tool, the model was found to be valuable for exploring changes over time of catchment rainfall-runoff response processes, especially with regard to their impact on flood peak discharges.

## REFERENCES

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