General enquiries on this form should be made to:
Defra, Science Directorate, Management Support and Finance Team,
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E-mail: research.competitions@defra.gsi.gov.uk

SID 5 Research Project Final Report

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Project identification

1. Defra Project code: FD2105

2. Project title: Improved Methods for National Spatial-Temporal Rainfall and Evaporation Modelling for BSM

3. Contractor organisation(s):
   Department of Civil and Environmental Engineering, Imperial College London

   Department of Statistical Science, University College London

   Centre for Ecology and Hydrology, Wallingford

4. Total Defra project costs: £ £683,249.00

5. Project: start date .... 01 November 2001

   end date .... 31 October 2005

6. It is Defra’s intention to publish this form.
Please confirm your agreement to do so...YES ☒ NO ☐

(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

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In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

(b) If you have answered NO, please explain why the Final report should not be released into public domain

NA

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Continuous simulation rainfall-runoff models have some important advantages over conventional event-based methods for flood estimation, but require long sequences of rainfall and evaporation data as input. This project has investigated a range of approaches for stochastic rainfall and evaporation simulation.

Single-site rainfall models can be used to simulate data from individual raingauges or catchment-average time series. A comparative analysis of single site models has been made, based on representative UK raingauge data, using methods based on Poisson Cluster processes. The 6 parameter Random Parameter Bartlett Lewis model is recommended for general application; more complex models have greater parameter uncertainty. Model fitting can be problematic. A new 2-stage fitting procedure has been developed to improve the fitting of extremes. Joint testing of rainfall and FDF2106 rainfall-runoff methods was undertaken.

Methods were also developed to model daily sequences of Potential Evaporation (PE), conditional on rainfall, based on nationally available data products such as MORECS. These can a) model weekly PE given rainfall, b) model daily PE given rainfall, c) downscale weekly to daily PE.

More generally, modelling of spatial rather than single site rainfall is required. A software package has been developed based on Generalised Linear Models (GLMs) to simulate the spatial distribution of daily rainfall from daily raingauge networks. Long sequences can be generated, or the model can be used to infill missing data. These models can represent spatial effects, such as topography, and climate variability. Effects of climatic indicators such as the North Atlantic Oscillation can be incorporated to produce time varying rainfall frequency distributions. In a sister project (FD2113), these models are being used to produce daily rainfall from Global and Regional Climate Models. The project carried out tests on 2 UK networks; a further independent application to the river Ouse is reported.

For flood modelling, hourly spatial data may be needed. In typical applications, a network of daily raingauges is available, plus a small number of sub-daily gauges. Hence a spatial temporal disaggregation procedure has been developed. A simple assumption is made, that the subdaily temporal distribution from a central location can be applied to the whole catchment, but scaled to reproduce the spatial distribution of daily data. This method can be based wholly on observed data, or wholly on simulated data. In the simulation scheme, the daily spatial rainfall is generated using a GLM, and at a central location the daily data is downscaled to hourly, using Poisson Cluster models within a package called HYETOS. Tests of the procedure are reported, for the Lee catchment, North London, with respect to rainfall properties and semi-distributed rainfall-runoff simulation.

More generally, extension of the Poisson cluster methods used for single site modelling to two dimensions provides models that can generated rainfall in continuous space and time, and hence at any requires time and space scale. These provide the most complete representation of rainfall fields, but radar data are required to capture the full clustering structure of the rainfall. The project has thus generated a 13 year recalibrated radar sequence (for the Chenies radar), and further developed continuous space-time models. In particular new approaches to represent spatial non-stationarity have been explored for the first time. The simulation results are impressive, but parameter identification issues remain problematic. Wider application of these models requires increased availability of radar data and further development and testing is required before the model could be recommended for general application.

The issue of the required information to characterise rainfall spatial variability for rainfall runoff modelling has been explored. A review of the international literature is presented, and a numerical study has been carried out using event modelling for the River Lee. The issues are complex; catchment sensitivity to spatial rainfall depends on rainfall type, catchment characteristics, and spatial scale. For the Lee, there is evidence that as catchment scale increases, the damping effects of runoff processes increasingly mask rainfall variability. Spatial rainfall properties are most important for urban catchments and convective storm events.

User Guidance

Of the models developed, software is made available for those that were considered to be ready for use within the UK given the testing in this report. It is hoped that researchers and practitioners will be able to make use of these tools and provide feedback on their experience.

Three software products are to be made available:
Single-site hourly rainfall model: Random Parameter Bartlett-Lewis Model (RPBLM)
Multi-site daily rainfall model: Generalized Linear Model (GLM)
Disaggregation of multi-site daily rainfall to hourly module: GLM with HYETOS temporal disaggregation procedure

Single-site hourly rainfall model
The Random-Parameter Bartlett-Lewis model with an exponential distribution for cell intensities was chosen for application across the UK based on a series of individual tests for sites representative of rainfall across the UK. The model can be used to represent rainfall at an individual gauge or a catchment average rainfall.

For individual raingauges (using hourly data), parameter identification has proved a challenge and a new two-stage fitting method has been developed. Overall, the models are able to reproduce a wide range of statistical properties of rainfall, with monthly seasonality, including monthly and annual extremes. However, for some sites extreme value performance is poor. We conclude that the model and optimisation technique are appropriate for use with caution, with the user undertaking careful verification of the simulated outputs. More extensive testing is required on a wider range of sites before the model can be recommended for general application across the UK.

For catchment average hourly rainfall, some issues arise where the sub-daily model properties are based on an individual sub-daily raingauge and the daily properties on a spatial average. These remain to be explored. However, the joint performance analysis (i.e. of rainfall and rainfall-runoff models) based on three catchments has shown encouraging performance.

Multi-site daily rainfall model
The generalised linear models have been applied to several networks of daily raingauges in the UK and Ireland including applications in flood design studies. They can simulate long sequences of daily rainfall across a network of sites including effect of spatial location (e.g. topography, rainshadow) and temporal non-stationarity including climate change. Climatic predictors such as the North Atlantic Oscillation can be built in to the model and a time varying probability distribution of extremes can be generated. The models can also be used to infill missing data from a network of gauges.

The report includes an application of the software to the Ouse catchment by a non-experienced user and provides some guidance not only to model performance but also to the user's experience of the software. The software is available with user manual.

Disaggregation of multi-site daily rainfall to hourly spatial rainfall
A procedure has been developed to generate a spatial distribution of subdaily rainfall for the typical situation where a network of daily raingauges exists and limited sub-daily data. Observed daily data can be used directly, or long sequences can be generated using the GLM approach above. The basic concept is simple; a single sub-daily time-series is applied to each location of interest with appropriate linear scaling to match the daily total at that point. Observed sub-daily data can be used, or alternatively a modelling procedure based on the Poisson cluster models.

The simple concept of spatial transposition of the temporal sub-daily sequence has been shown to perform well for the River Lee catchment in North London. The combined modelling procedure reproduces spatial daily rainfall properties and point sub-daily properties well, but as expected tends to overestimate spatially averaged annual hourly rainfall maxima (due to the coincidence of the sub-daily rainfall profiles). Nevertheless, the combined procedure based on observed daily data and a single observed sub-daily profile performs well when used as input to a semi-distributed event based rainfall-runoff model. The method appears to be extremely promising, and to have wide applicability.

With respect to the software, a fully integrated procedure is not yet available in suitable form for release. However, the GLM software is available as discussed above and the temporal disaggregation software is available as a package HYETOS (developed outside this programme).

Other procedures developed within this project
The remaining modelling software discussed in this report is not considered to be in a suitable form for general availability at present.

The software for model fitting and simulation will be available through the project website: http://www.imperial.ac.uk/ewre/research/currentresearch/hydrology/improvedmethods

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Single site models: c.onof@imperial.ac.uk
GLMs for spatial daily rainfall: richard@stats.ucl.ac.uk
Spatial-temporal disaggregation: c.onof@imperial.ac.uk
Continuous space-time rainfall models: valerie@stats.ucl.ac.uk
Evaporation methods: richard@stats.ucl.ac.uk

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

See attached FD2105_SID5_project_report.doc.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Project Technical report

Wheater, H. S., Isham, V. S., Chandler, R. E., Onof, C. J., Stewart, E. J., Bellone, E., Yang, C., Lekkas, D., Lourmas, G., Segond, M-L, Frost, A. J., Prudhomme, C., Crooks, S. (2005) Improved methods for national spatial-temporal rainfall and evaporation modelling for BSM. R&D Technical Report F2105/TR. Defra.

Internationally refereed material

Chandler, R. E. and Wheater, H. S. (2002). Analysis of rainfall variability using Generalized Linear Models — a case study from the West of Ireland. Water Resources Research, 38, No.10:doi:10.1029/2001WR000906.

Wheater, H. S., Chandler, R. E., Onof, C. J., Isham, V. S., Bellone, E., Yang, C., Lekkas, D., Lourmas, G., and Segond, M.-L. (2006). Spatial-temporal rainfall modelling for flood risk estimation. Stoch. Env. Res. & Risk Ass., In press.

Yang, C., Chandler, R. E., Isham, V. S., and Wheater, H. S. (2006a). Quality control for daily observational rainfall series in the UK. CIWEM, To appear.

Yang, C., Chandler, R. E., Isham, V. S., and Wheater, H. S. (2006b). Spatial-temporal rainfall simulation using generalized linear models. Water Resources Research, In press.

Project website address

http://www.imperial.ac.uk/ewre/research/currentresearch/hydrology/improvedmethods

(Internal technical reports along with final technical report can be downloaded from this address)