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HRPP 339

National flood hazard mapping for Scotland - an innovative approach

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Reproduced from a paper published in:
Proceedings of the 40th Defra Flood and Coastal Management Conference
5th to 7th July 2005
University of York, UK

NATIONAL FLOOD HAZARD MAPPING FOR SCOTLAND - AN INNOVATIVE APPROACH

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Abstract

National-scale fluvial and coastal water level prediction and flood extent mapping is an essential planning tool for the management of flood risks through strategic planning, risk mapping, land-use development and management of flood defences. The Scottish Environment Protection Agency has commissioned HR Wallingford to provide an innovative, semi-automated, robust approach for the prediction of flood hazard maps for Scotland. These include flood events with a 1.0%, 0.5% and 0.1% annual probability of occurrence in the absence of defences. The methodology is based on state of the art GIS scripts developed in-house for handling and processing large volumes of data. The hydraulic calculation incorporates the latest R&D research such as the new EA/Defra Conveyance Estimation System (CES) software, recent initiatives for the assessment of uncertainty and an independent study to establish the likelihood of the Digital Terrain Model (DTM) identifying the channel bed, through consideration of bankfull discharge. The InfoWorks RS (IWRS) 1D hydrodynamic modelling software is used for simulating the hydraulics and for flood spreading. The method is designed to readily incorporate existing more detailed hydraulic models, information on previous flooding and local flood defence data. This paper describes the complete flood mapping methodology.

Keywords

National scale, flood hazard mapping, semi-automated

1. Introduction - second generation flood map (Scotland)

The Scottish Environment Protection Agency (SEPA) has commissioned HR Wallingford to develop a Second Generation Flood Map for Scotland for delivery in September 2005. The primary project objective is to prepare flood maps for all river catchments in Scotland with an area greater than 3km^2 for flood events with a 1.0%, 0.5% and 0.1% probability of occurrence. The downstream limit of the flood mapping is taken as the tidal limit as defined by the Centre of Ecology and Hydrology (CEH) Flow Grid. Historically, most flood mapping studies have been carried out for engineering or development control purposes, where detailed hydrological modelling and mapping techniques have been used. Application of such methods can cost upwards of £1000 per kilometre, particularly if the acquisition of survey data is taken into account. Here, a method is required for approximately 50,000km of river, based on national data sets, and thus localised details such as hydraulic structures, flood defences, off-line storage and detailed hydrology analyses are not considered. State of the art GIS scripts have been developed for handling and processing these large data sets. The hydraulic calculation is based on the latest EA/Defra R&D research (Defra/EA, 2003) and the IWRS (WS, 2005) 1D modelling suite is used for simulating the flood spreading. The flood outlines are therefore "broad-scale indicative" outlines based on a semi-automated approach rather than the product of accurate modelling techniques.

The methodology has been designed to incorporate future enhancements such as improved base data, flood defence information, coastal floodplains and detailed localised models through, for example, significant low-lying urban areas.

The final flood outlines will be made available to the public through provision of a web site where the flood hazard maps can be accessed via the Internet. For this, HR Wallingford has sub-contracted the Internet Delivery to Multimap, a well-established provider of mapping services on the Internet (www.multimap.com).

This paper provides an insight into the details of the innovative, semi-automated modelling approach, together with an overview of the uncertainty with respect to data quality, timeframe for delivery and the shear scale of the task. Future enhancements and application of the methodology to other national data sets are briefly discussed.

2. The challenge

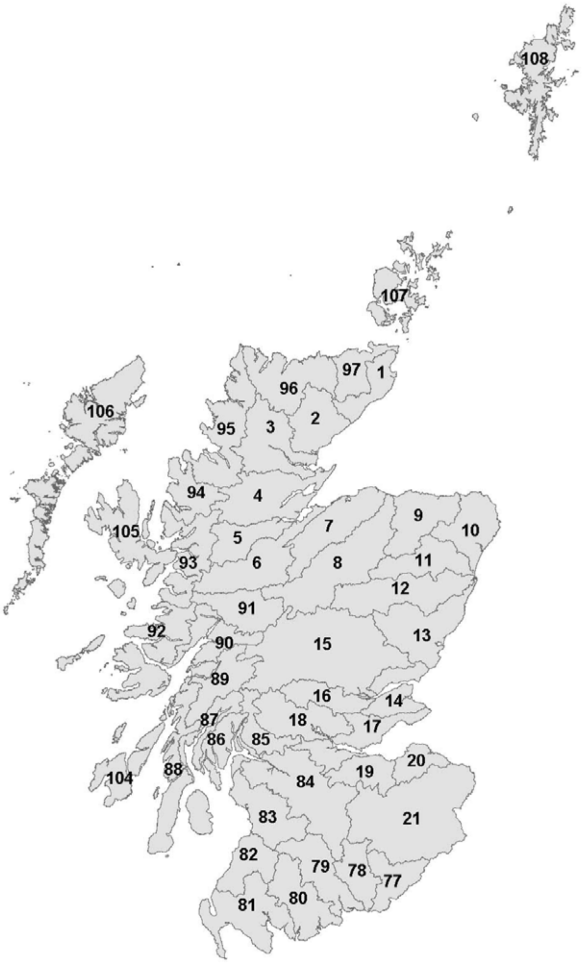
Providing a method for the national flood mapping of Scotland provides a challenge on various levels:

- **Scale**: the spatial (i.e. the whole of Scotland) and time (100, 200 and 1000 year flood events) scales for the modelling. Scotland has a total land area of 77,000km^2, comprising 47 Hydrometric Areas inclusive of the Islands (Figure 2.1), 50,000km of sizeable rivers, numerous large Lochs providing flood attenuation, varying relief from steep mountainous regions to low-lying cities such as Perth and a population of 5 million (GROS, 2001) potentially interested in the flood mapping results. The time scale is relevant as the flood events correspond to large return periods i.e. 100, 200 and 1000 years. There is thus limited data available for previous flood events of these magnitudes, providing a challenge for estimation of the flood flows and calibrating flood outline predictions, as well as uncertainty regarding the likelihood of these events actually taking place in the expected lifetime of the model output use.

- **Data**: combining extensive data sets from different sources and of varying quality in order to optimise the fluvial system representation within the hydraulic model. The base data sets for Scotland include the:

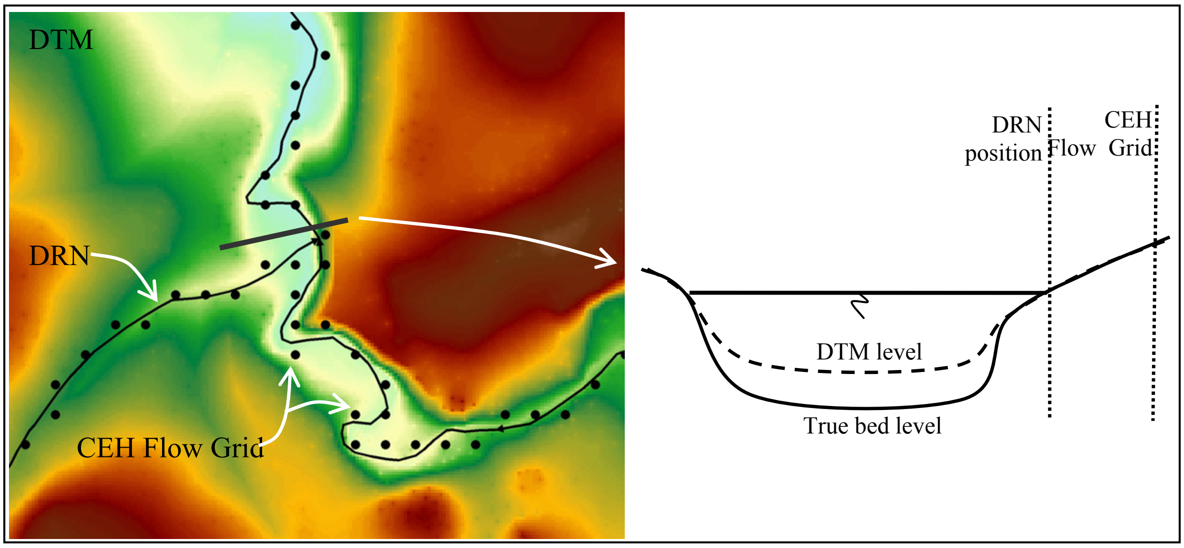
  1) CEH Flow Grid, which is a national implementation of the Flood Estimation Handbook (FEH) captured on a 50m square grid.
  2) Directional River Network (DRN) which consists of river centrelines and flow directions.
  3) Digital Terrain Model (DTM) derived from Synthetic Aperture Radar (SAR) which provides ground elevations in a digital raster format at a 5m grid resolution, with a horizontal and vertical error of ±2.5m and ±1.5m (RMS) respectively.
  4) Land Cover Map (LCM) 2000 which provides 25 land cover categories in digital format, represented as polygons or ‘parcels’ of similar land-use.
  5) FEH outflow direction grid which provides one of the eight primary compass directions to each flow point.
  6) Lakeshores data set which consists of polygons representing the area coverage of all Lochs and other isolated water bodies.

Figure 2 provides an example of the difficulty in combining the first three of these data sets.



Hydrometric Area	Area covered
1 to 5	North-East Highlands
6	River Ness catchment
7	Moray
8	River Spey catchment
9, 10	North-East Aberdeenshire
11	River Don catchment
12	River Dee catchment
13, 14	Angus
15	River Tay catchment
16	River Earn catchment
17 to 20	River Forth and tributaries
21	River Tweed catchment
77 to 83	South-West Scotland
84	River Clyde catchment
85 to 90	West Highlands
91	River Lochy catchment
92 to 95	North-West Highlands
96, 97	North Coast
104 to 108	Islands (Western Isles, Orkney & Shetland)

Figure 1 47 Hydrometric Areas in Scotland



(a) plan view (b) cross-section view

Figure 2 (a) Plan and (b) cross-section view showing an example where the DTM, DRN and CEH Flow Grid data all predict a different channel centreline

- **Method**: provision of a semi-automated, robust and defensible method that can be readily applied throughout the country. A key factor here is that an automated method anticipates data in a particular format, whereas in reality, the data is characterised with unusual features such as circular channels, multiple exit catchments, Q100 events larger than Q200 events etc.
- **Timeframe**: provision of flood outlines for delivery in September 2005.
- **Future enhancements**: providing a method that can readily incorporate future enhancements such as flood defence data and coastal flood outlines
- **Flexibility**: provision of a method that may be extended for application to improved or other national data sets
- **Long-term considerations**: provision of output that supports regional and national analyses such as Foresight (OST, 2004).

3. Methodology

Various approaches were considered for the hydraulic calculation. The Institute of Hydrology Report 130 (IoH, 1996) flood outlines for Scotland were produced in the mid-1990s and were a significant innovation at the time. This approach has however been superseded by the availability of improved national data sets.

The Environment Agency's 'Flood Zones' project for fluvial areas makes use of the 'CEH Flow Grid' together with the NextMap DTM and a 'raster-based' flood spreading model called JFLOW (JBA, 2003). This type of approach was not adopted because of the lack of a direct upgrade path.

The Risk Assessment for Strategic Planning (RASP) approach was considered, but was not considered suitable because it is primarily aimed at flood risk in defended areas. The adopted method is based on a 'normal depth' hydraulic calculation. The great strength of this method is that it is based on standard hydraulic calculations that are transparent and can be updated by hydraulic modelling where required. The method has been applied to the Norwich Union flood maps for England and Wales.

The methodology can be broadly divided into seven stages, which describe the complete modelling process from raw data processing through to the final Internet Delivery:

1. **Pre-processing data** involves combining and processing the data sets, within an ArcGIS environment, into a format suitable for use in the CES and the 1D hydrodynamic modelling software, IWRS.
2. **Hydraulic model build** is where the conveyance curves for each cross-section are calculated within the CES software and then imported into the IWRS model, which is automatically built from the pre-processed data, with channel cross-sections, inflow boundary conditions, roughness allocations, bed markers and ground model data.
3. **Normal depth simulation** involves running the hydraulic models for the 100, 200 and 1000 year return period events, using the Muskingum-Cunge flood routing method as a simple tool for calculating the longitudinal water profile. The IWRS flood spreading routine is employed to determine the flood extents based on water level and ground model information.
4. **Backwater simulation,** which will be applied to 13 tidal and 8 inland sites throughout Scotland, involves converting the downstream boundary condition to the provided gauged level or Highest Astronomical Tide (HAT) level for that reach, and simulating a backwater calculation for each of the three events. The IWRS flood spreading routine is employed to determine the flood extents.
5. **Post-processing flood outlines** to collate the IWRS output, remove isolated pockets of water and merge the outlines for each event with the Lakeshores data set.
6. **Attribution of uncertainty** is a review phase, where the flood mapping outputs are assessed in terms of data anomalies, method limitations and comparison to flood outlines from previous

observations or localised more detailed models. The results are flagged, based on a qualitative scale, to indicate the reliability of the result for a given reach.

7. **Internet delivery** involves provision of a web site for viewing the flood outline results.

The methodology is applied to complete Hydrometric Areas rather than individual catchments. The remainder of this section describes the seven stages in more detail.

1.1 Pre-processing of data

The CEH flow grid is provided for the whole of Scotland, and thus the first stage is to reduce the data set to flow points for catchments with areas greater than 3km$^{2.}$ These flow points are then assigned to the closest DRN reach.

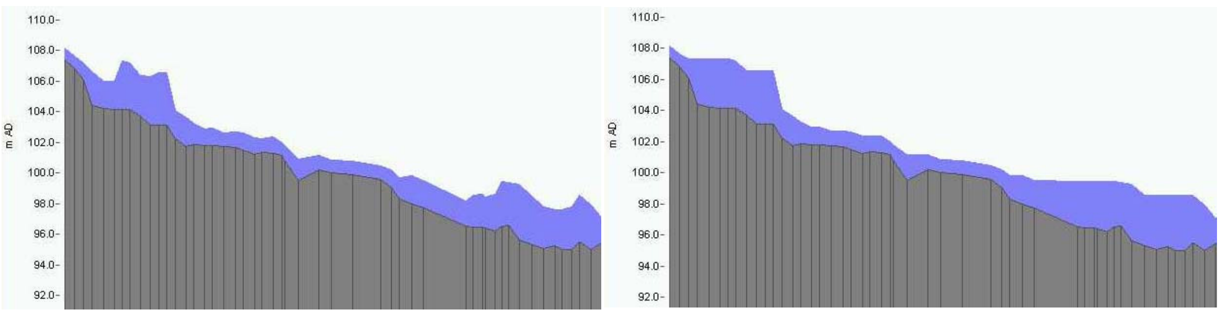
A key step in the DRN processing is the stream ordering, whereby the river system is divided into tributary based orders, which are modelled independently in the IWRS model. This reduces the likelihood of cross-sections overlapping at confluences.

The channel cross-sections are generated perpendicular to a smoothed valley centreline, to reduce the likelihood of overlapping cross-sections in meandering reaches. The DTM information is used to establish the cross-section elevations, with wider cross-sections in the low-lying areas and narrow cross-sections in steep mountainous reaches.

Channel roughness is required for the CES conveyance calculation. This is derived from the Land Cover Map data set, where each of the 25 land-use categories is assigned a unit roughness value based on the CES Roughness Advisor description.

1.2 Hydraulic model build

The cross-section and roughness information is imported into the CES software to calculate the cross-section conveyance. This information, together with the pre-processing data output, is used to automatically generate the river network and event data within the IWRS environment. The network consists of a series of cross-sections with lateral inflow boundaries, emulating the cumulative inflow along the reach. A key stage in the IWRS model build is that the connectivity along the reach is used to determine whether a cross-section further downstream will have a greater water level for the given event than the upstream cross-section of interest. Where this occurs, the upstream cross-section's conveyance curve is updated to reflect this greater water level. This ensures that the water level along the reach will not increase in the downstream flow direction (Figure 3).



(a) Before (b) After

Figure 3 Long profile of reach water levels (a) before and (b) after the water level correction is applied

3.3 Normal depth simulation

The normal depth phase involves simulating each event, using the Muskingum-Cunge routing approach as a tool for converting the water levels at each section into a complete longitudinal water profile. It should be emphasised that the event data used in the hydraulic calculation is based on the total flow rate for the given event i.e. the DTM data is assumed to identify the channel bed rather than the water surface (HRW, 2005). The calculated water levels and the ground model elevations are used within the IWRS flood compartments, which designate the allowable floodable region, for calculating the extent of the flood spreading (Figure 4).

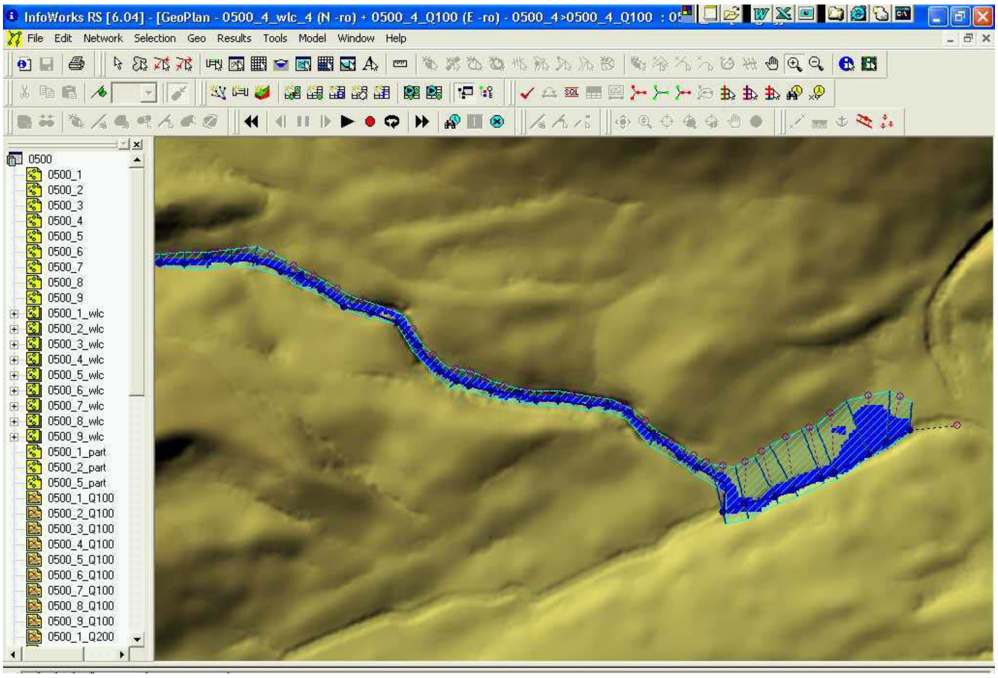


Figure 4 Example of an IWRS model reach illustrating the flood compartments and flood spreading

3.4 Backwater simulation

The backwater calculation is implemented for 21 sites across the whole of Scotland, and is, as such, outside the core project methodology. It does, however, illustrate the ease with which the models can be upgraded to simulate full backwater calculations provided the downstream boundary conditions are known. The main tidal reaches include Glasgow, Irvine, Dumfries, Stirling, Perth, Aberdeen, Elgin and Inverness and main inland reaches include the Sills of Clyde and the confluence of the Tay and Isla Rivers. The backwater models are created by identifying the reach of interest within the IWRS model, using a simple rule of thumb approach (Samuels, 1989) to ensure the extent of the backwater is not felt further upstream and hence creating a localised network for that reach. The Muskingum-Cunge sections are converted to equivalent river sections, and the downstream boundary condition is attached. The hydraulic simulation uses the trans-critical solver, as the reach may encounter small steep sections with supercritical flow, and this allows for the switch between the supercritical and subcritical flow conditions. Thereafter, the flood spreading routine is identical to that implemented in the normal depth approach.

3.5 Post-processing flood outlines

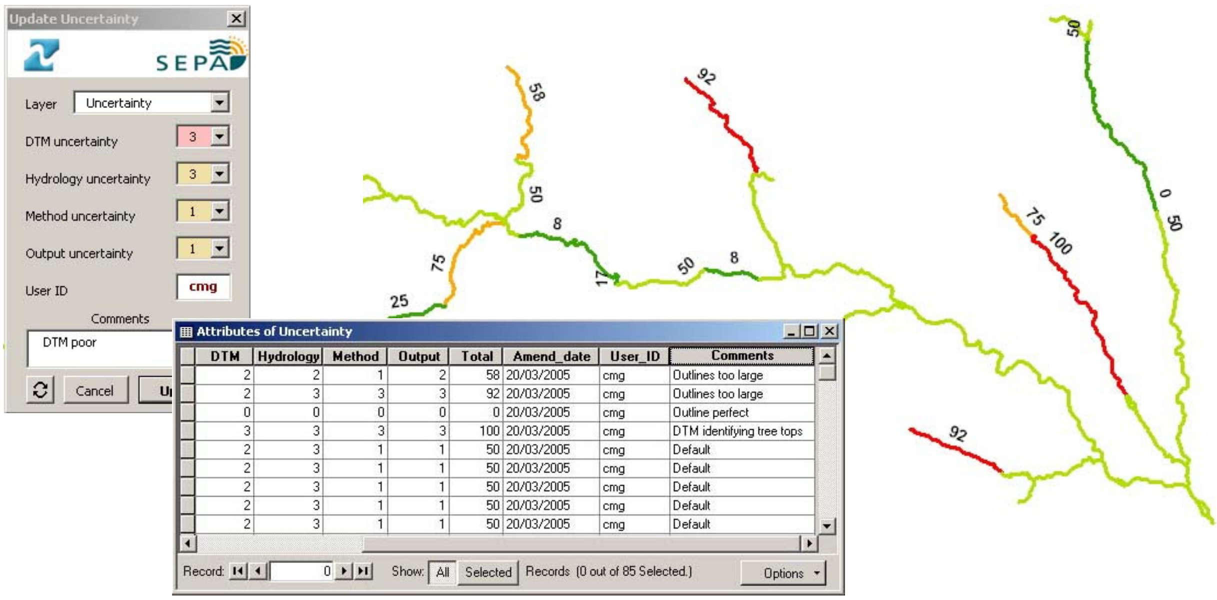
The IWRS flood outlines are post-processed in an ArcGIS environment. The raw flood outlines are collated, geo-referenced and any isolated pockets of water that are remote from the DRN are removed. For each event, the flood outline results for all stream orders are merged and any internal seams are dissolved to ensure a single continuous polygon outline. The Lakeshores data set is then merged with the flood outlines, such that any inline water bodies are included in the final flood map.

3.6 Attribution of uncertainty

A fundamental component of the methodology is reviewing the reliability of the results and attributing some measure of uncertainty which relates this reliability to the input data, the discrepancies due to features of the methodology and comparison of the final flood hazard maps to previous observations and detailed model predictions. The uncertainty is represented with a qualitative flag, which is shown as an overlay to the DRN, providing a reach-based uncertainty value. Four uncertainty components have been identified: DTM quality, Hydrology, Methodology and Output, and are assigned an uncertainty value from 0 (low) to 3 (high). The default values for the Hydrology and DTM are high, 2 and 3 respectively, as these are considered the primary source of uncertainty. The review phase allows the modeller to overwrite these default values along reaches based on an assessment of the quality of each input parameter and the final output (Figure 5). A total uncertainty score is obtained by adding the four component uncertainties and expressing it as a percentage of the maximum allowable score of 12. This simplified approach ignores interdependencies between the uncertainty components and the fact that these uncertainties may relate to over or under estimation of the flood levels, where the net effect is reduced or null.

3.7 Internet delivery

The Internet delivery, which is subcontracted to Multimap, will provide users with a navigable map of Scotland (e.g. Figure 6) with zoom capability showing the flood outlines overlaid on the map. The gazetteer will include standard search facilities such as places names and post codes. The flood outlines for the three events will be available, as well as information about the flood outline methodology and interpretation of results. The uncertainty data will not be made available in the public domain.



DTM	Hydrology	Method	Output	Total	Amend_date	User_ID	Comments
2	2	1	2	58	20/03/2005	cmg	Outlines too large
2	3	3	3	92	20/03/2005	cmg	Outlines too large
0	0	0	0	0	20/03/2005	cmg	Outline perfect
3	3	3	3	100	20/03/2005	cmg	DTM identifying tree tops
2	3	1	1	50	20/03/2005	cmg	Default
2	3	1	1	50	20/03/2005	cmg	Default
2	3	1	1	50	20/03/2005	cmg	Default
2	3	1	1	50	20/03/2005	cmg	Default
2	3	1	1	50	20/03/2005	cmg	Default

Figure 5 Example of the uncertainty representation

Figure 6 Sample screen shot of how the web site may look

4. Sources of uncertainty

Implementation of the complete methodology will produce flood outlines which are subject to a degree of uncertainty. As the flood hazard maps will be available to all on a national scale, the fundamental question for end users is "how reliable are the flood outline results?". To best answer this question, it is necessary to identify, understand and interpret the various sources of uncertainty and their potential impact on the result. Uncertainty is introduced at each level of the modelling process:

- **Conceptual modelling** involves a thorough inspection of the entire "real world" fluvial system and identification of the important channel and floodplain flow processes to be modelled. These are typically those that contribute substantially to the end result that are within the scope and resource of the project specification.
- **Schematisation** is where the physical fluvial system is broken down or "schematised" into analogous units which can be readily handled within a modelling system, for example, discrete DTM elevation data at 5m grid intervals representing the true continuous topography or single channel cross-sections representing a 50m river reach.
- **Data and measurement** refers to the availability and quality of the input data. This is largely related to the method of measurement, for example SAR versus LiDAR data, and the conditions under which these were made.
- **Mathematical modelling** is introduced to represent the flow processes, where possible, with equations. Here, the model is only as valuable as the degree to which it reproduces the occurrence and structure of the true flow features. The hydraulic calculation used in the SEPA methodology is based on the latest EA/Defra R&D conveyance approach.
- **Numerical modelling** is introduced as an alternative option to a direct analytical solution in solving the mathematical equations. Here, a solution is obtained by discretising the equations with simple finite difference or finite element approximations. In the conveyance, flood-routing and backwater calculations a numerical solution is employed.
- **Computational modelling** provides an efficient method for solving numerical equations, however uncertainty is introduced as the system is limited by the allowable precision.

Thus various uncertainty sources are introduced throughout the overall modelling process which may influence the output, and hence its reliability. For the SEPA flood outline methodology, the primary source of uncertainty is the data and the remainder of this section describes this in more detail.

4.1 Flow estimates in the CEH Flow Grid

The CEH Flow Grid has been derived by a consistent implementation of the FEH methods. However, the data used to develop the Flow Grid does not take into account flow data obtained in recent years (particularly since 1998, when there have been a number of major floods in parts of the UK). In addition, the extent to which local data can be taken into account is limited by the general nature of the method.

Comparisons between hydrological predictions from the Flow Grid and detailed model studies have shown that significant differences of 20% or more can exist. This reflects the uncertainty of flood hydrology, where even the base data (i.e. measurement of flood flows) can be subject to considerable error.

This problem can be addressed by using better local flow data where available. However, any data that is used must be applicable to whole catchments and must provide flows for the three flood probabilities under consideration in this study.

4.2 River alignment in the CEH Flow Grid

There are errors in river alignment in the CEH Flow. This derives from the methods used to develop the Flow Grid, based on the use of a DTM to derive drainage paths. It is understood that these errors have been removed in the preparation of the DRN, and this is therefore assumed to be the correct flow path in the SEPA methodology.

An example of a flow path error is shown in Figure 7. Such errors result in catchment areas (and therefore flows) for some rivers being too large, while for the true catchment they are underestimated.

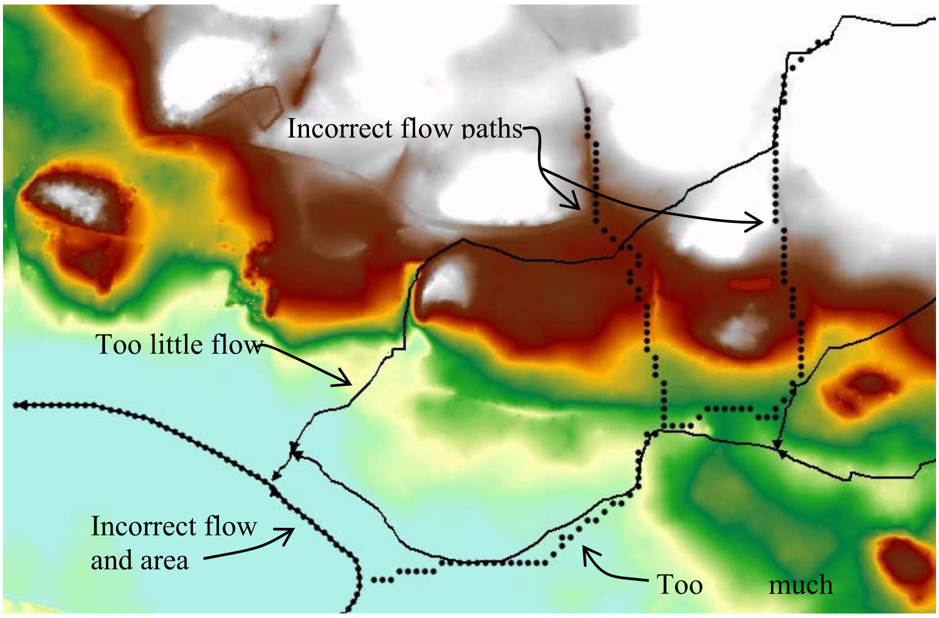


Figure 7 Example of a CEH Flow Grid path error

4.3 Quality of the DTM

The OS Profile DTM was originally intended to be used for catchment modelling during the implementation of Catchment Flood Management Plans in England and Wales. However, pilot studies identified large discrepancies in the ground data in the form of steps, typically up to 5m in height. As a result, both the Environment Agency and SEPA decided to use the Nextmap DTM, which was already being used by Norwich Union Insurance for their national flood mapping programme. Whilst this DTM provides a more consistent ground model, there are still errors arising from the way in which the data are collected and edited. These include:

- A variable error in the DTM compared with absolute levels. This is believed to be less than one metre and will not affect the method used in the SEPA project, where modelling and mapping is carried out using the same DTM. It will however affect the import of levels from other sources.
- Errors arising from editing, caused by vegetation and other obstructions. This can be particularly serious in urban areas, where data collection radar signals are affected by buildings and other features of the urban environment. This can lead to the following types of error:
  - Humps in the ground surface (or depressions, where the editor has over-compensated when removing a group of trees or other obstruction)
  - Errors in level over significant areas, for example in some urban areas
  - Errors in the channel shape. Generally the DTM does not identify river channels (as it only records the water surface), but where the channel is obscured by trees a channel is introduced during the editing to provide a continuous downhill flow path. Often these channels can be far too large (or small depending on the depth of flow). Figure 8 shows a comparison between the DTM and survey data at a location where there is no vegetation and therefore no apparent reason for differences. This clearly illustrates concerns over the accuracy of the DTM.

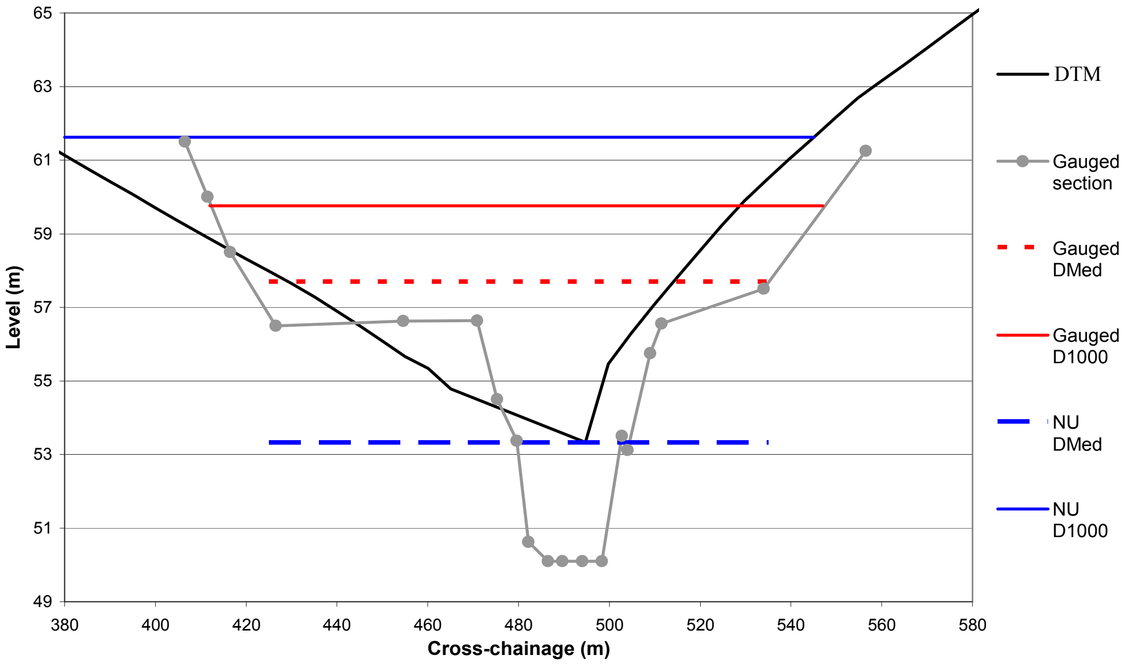


Figure 8 Nextmap DTM data compared with survey data at Montford Bridge on the River Severn

4.4 Active flow area for the hydraulic calculation

An important consideration in the hydraulic calculation is what portion of the river channel is identified by the DTM. If the DTM identifies the water surface, the channel capacity will be reduced. The depth of water at the time of survey will determine the amount of this reduction. Previous studies typically assume the DTM captures the channel at bankfull depth, and that the flow domain is essentially the channel valley excluding the inbank portion. Thus, the flow rates for the 100, 200 and 1000 year return period event are reduced by the assumed bankfull flow rate. The simplest approach is to relate this to the two year return period event, Q_{MED}. In practice, the in-channel bankfull capacity varies, but the variation is considered to be small compared with the flood events used for the mapping. The assumptions inherent in reducing the flow rate by Q_{MED} are that:

- the DTM survey was undertaken when the channel was flowing at approximately bankfull depth,
- the DTM did not penetrate through to the channel bed and
- the bankfull discharge can be related to Q_{MED}

For this study, the validity of these assumptions was considered for the Kelvin Catchment (HRW, 2005) and the findings were that:

- Q_{MED} is large relative to Q100 (30-40%), and thus the decision to include or exclude Q_{MED} is significant,
- the impact on resulting flood outlines is substantially larger in low-lying reaches than mountainous streams,
- detailed cross-section analysis and consideration of bankfull discharge revealed that, in most cases, the DTM was penetrating through to the channel bed and
- the literature suggests that the ratio of bankfull discharge to Q_{MED} is approximately 0.65, but this value has a high degree of variability.

Based on these findings, the flood events in the SEPA methodology are not reduced by the Q_{MED} flow rate, and this may result in overestimated flows in some reaches.

5. Future enhancements

5.1 Benefits of a modelling based approach

The IWRS modelling based approach provides potential benefits such as:

- An appropriate range of solution techniques including Flow Routing, Steady State (Backwater) and Unsteady Flow. The latter allows for inclusion of flood embankments and off-line storage.
- A product based solution, developed to commercial standards.
- A future proofed solution, capable of updating to more advanced solution techniques as these become available.
- A full audit trail of the modelling process, providing user ability to review current and historical model versions and data by storing information within a database environment.
- A multi-user, workgroup based solution, providing access to models stored in a central 'master' database to a range of users.
- Close integration with other key IT Systems, for example, existing corporate relational databases (e.g. oracle) and GIS.
- Maximising use and re-use of models, for example, existing models can be brought into the system over time to provide improved estimates of flood extents at key locations

This flexibility supports a range of possible enhancements to the reliability of the mapping process.

5.2 Extension to include the coastal flood hazards

The flood hazard mapping can be extended to include coastal floodplains and the tidal-fluvial interaction zone, ideally employing joint probability methods and tidal modelling.

5.3 Integration of the modelling methods with development of an asset database

Wallingford Software provide a bespoke package, InfoNet, aimed at managing asset data. This product provides a structured framework for managing all types of water related assets and is specifically designed to link with GIS and other IWRS and FloodWorks products. InfoNet is already used by the Regional Government in Northern Ireland to manage some of their water related infrastructure. There is therefore opportunity with the SEPA methodology to develop databases and modelling frameworks in an open but consistent fashion.

5.4 Extension to include flood defences

The SEPA methodology provides a platform for moving forward to the development of flood hazard maps, assuming the availability of asset data and asset descriptors stored in a well ordered data structure. This would involve application of the RASP methodologies, employed by the Environment Agency in England and Wales, to map flood hazard in defended areas.

5.5 Enhancement of delivery options

Enhancement of delivery options may include:

- Capturing feedback from users effectively, for example, user feedback that writes directly to a database and could then be reported along with site usage statistics as a written report or map based information.
- Use of live flood data. For example, SEPA has data on catchments corresponding to ‘flood watch’, ‘flood warning’, ‘severe flood warning’ and ‘all clear’, which is relatively straightforward to incorporate as a polygon or flood warning symbol on a base map.
- Use of mobile devices. Multimap services are now available on WAP (Wireless Application Protocol) phones and related mobile devices. The WAP platform gives users of wireless devices easy access to live interactive information services and maps. This again could provide a useful method for communicating both flood hazard maps and, more importantly, flood warning information.

6. Application to other national data sets

The SEPA methodology is designed to incorporate four core base data sets: the CEH Flow Grid, the DTM, the LCM and the DRN, and process and interpret these into a format that best represents the fluvial system and can be readily imported into a hydraulic model. The methodology is flexible in that it can be applied to similar data sets from other sources, for example:

- The flow data can be represented by any point data set, where the flows are located within reasonable proximity of the associated flow path.
- Raster topography data which can be derived from triangulation of surface elevations from any source (e.g. LiDAR, survey).
- The LCM map data can be replaced with any plan form roughness information, such as Mastermap.
- The DRN is employed in the SEPA methodology, however, it is possible to derive flow paths from the Cumulative Catchment Area Grid or alternatively an outflow direction grid.

Once the data sets have been processed, the methodology in its existing form can be applied. The approach to uncertainty can be adapted with relative ease to include the identified uncertainty sources for the relevant data sets.

7. Conclusions

This paper presents the complete Scottish Environment Protection Agency methodology for producing flood hazard maps for the whole of Scotland. Key challenges include the scale of the application, provision of a defensible, semi-automated, robust approach based on sound hydraulics and the flexibility for future upgrades such as inclusion of asset data, coastal floodplains and more detailed localised models. The complete method comprises seven stages, ranging from raw data processing through to the final Internet delivery. Software applications include ArcGIS for data processing, the Conveyance Estimation System for calculating rating curves and InfoWorks RS for the hydraulic modelling. The approach incorporates a qualitative analysis and representation of the uncertainty associated with the complete modelling process, and as such, provides an indication of the reliability of the final flood outlines. The uncertainty sources are largely based on the input parameters, in particular, the CEH Flow Grid and the DTM. The advantage of incorporating the IWRS modelling suite is that there are clear upgrade paths for future modelling. The complete SEPA methodology can be extended for application to improved or alternative national data sets with relative ease.

8. Acknowledgements

This paper draws upon the Second Generation Flood Map for Scotland project commissioned by the Scottish Environment Protection Agency (SEPA) in April 2004. We wish to thank Dr Chris Fuller, the SEPA Project Manager, and the SEPA regional hydrologists for their ongoing encouragement and support. The contributions of all HR Wallingford team members, in particular Douglas Benwell, Romina Trombini and Quillon Harpham, are also gratefully acknowledged. The views expressed in this paper are, however, personal and the publication does not imply endorsement by SEPA.

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NOTES

Fluid thinking...smart solutions

HR Wallingford provides world-leading analysis, advice and support in engineering and environmental hydraulics, and in the management of water and the water environment. Created as the Hydraulics Research Station of the UK Government in 1947, the Company became a private entity in 1982, and has since operated as a independent, non profit distributing firm committed to building knowledge and solving problems, expertly and appropriately.

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