Updating the ReFH design method within Scotland

WHS & CEH Wallingford
Scottish Hydrological Group – 16th April 2014
1932  Unit hydrograph
1975  Flood Studies Report (Volume 1)
1977  18 Flood Studies Supplementary Reports
1988  IH Report 124 and 126
1995  Flood Estimation Handbook (Volume 4)
1999  The Revitalised FEH Rainfall-Runoff method
2005  The Revitalised FEH Rainfall-Runoff method v2
2014
FSR/FEH ➔ ReFH v1

- $Q_T (R-R) \gg Q_T$ (statistical)
- Observed CWI and PR not aligned with design values
- More large and recent events
- CWI calculated using outdated methods
- More objective methods for defining baseflow
- More process-based link between surface runoff and baseflow
- Loss model based on PDM model
- More flexible UH shape
- More realistic hydrograph shapes
ReFH v1 ➔ ReFH v2

- $\text{URBEXT}_{1990} \rightarrow \text{URBEXT}_{2000}$
- Urban processes not represented in v1
- Scottish data under-represented in v1
- ReFH v1 "alpha" parameter only calibrated to $T=150$ years
- Alpha performance related to SAAR
- ReFH v1 not to be used for BFIHOST > 0.65
- Scaling of parameters for use on small catchments (plot scale)
- BFIHOST ➔ BFIHOST_SCOTLAND
ReFH model structure

![Diagram of ReFH model structure]
Research Overview

Expansion of the catchment dataset within Scotland

Update of the design package within Scotland

- Parameter estimation: Eqns specific to Scotland & use of URBEXT\textsubscript{2000}
- Explicit representation of urbanisation
- \( C_{\text{ini}} \): adjustment for permeable catchments
- \textit{Design package: relationship between alpha and SAAR and calibration up to 1000 year return period}
Calibration approach

• Extensive QA of flow and rainfall data
• Minimum of 10 events > Qmed/2
• Independent evaluation events
• Multi-criteria objective function; event volume, peak flows, hydrograph shape.
<table>
<thead>
<tr>
<th></th>
<th>AREA</th>
<th>BFIHOST</th>
<th>DPLBAR</th>
<th>DPSBAR</th>
<th>PROPWET</th>
<th>SAAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ReFH v2 Scotland</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>min</td>
<td>2.07</td>
<td>0.30</td>
<td>1.64</td>
<td>29.9</td>
<td>0.42</td>
<td>833</td>
</tr>
<tr>
<td>Max</td>
<td>961.4</td>
<td>0.58</td>
<td>54.54</td>
<td>308.4</td>
<td>0.78</td>
<td>2769</td>
</tr>
<tr>
<td>Average</td>
<td>299.0</td>
<td>0.40</td>
<td>21.4</td>
<td>133.0</td>
<td>0.61</td>
<td>1343</td>
</tr>
<tr>
<td><strong>ReFH V1 Dataset</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>3.47</td>
<td>0.18</td>
<td>2.25</td>
<td>11.50</td>
<td>0.25</td>
<td>570</td>
</tr>
<tr>
<td>Max</td>
<td>510.90</td>
<td>0.78</td>
<td>38.49</td>
<td>210.40</td>
<td>0.71</td>
<td>2261</td>
</tr>
<tr>
<td>Average</td>
<td>174.08</td>
<td>0.45</td>
<td>16.28</td>
<td>80.91</td>
<td>0.43</td>
<td>1010</td>
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</tbody>
</table>
Estimation of Design Package Parameters

- Model form reassessed
- Statistically weight model by the number of events for each site
- Alternative formulations developed removing catchment geometric measures (e.g. replace DPLBAR with AREA)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
<th>R-squared</th>
<th>Factorial Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_p$</td>
<td>$T_p = aPROPWET^b DPLBAR^c (1 + urb2000)^d DPSBAR^e$</td>
<td>0.68</td>
<td>1.37</td>
</tr>
<tr>
<td>$T_p$</td>
<td>$T_p = aPROPWET^b Area^c (1 + urb2000)^d SAAR^e$</td>
<td>0.73</td>
<td>1.4</td>
</tr>
<tr>
<td>$C_{Max}$</td>
<td>$C_{Max} = aPROPWET^b \exp(cBFIHOST)$</td>
<td>0.57</td>
<td>1.15</td>
</tr>
<tr>
<td>$B_L$</td>
<td>$B_L = aPROPWET^b DPLBAR^c (1 + urb2000)^d BFIHOST^e$</td>
<td>0.72</td>
<td>1.2</td>
</tr>
<tr>
<td>$B_L$</td>
<td>$B_L = aPROPWET^b Area^c (1 + urb2000)^d BFIHOST^e$</td>
<td>0.73</td>
<td>1.2</td>
</tr>
<tr>
<td>$B_R$</td>
<td>$B_R = aPROPWET^b BFIHOST^c$</td>
<td>0.22</td>
<td>1.4</td>
</tr>
</tbody>
</table>
ReFH ≠ Statistical method

- reducing the rainfall depth as return period increases;
- specifying increasingly dry initial soil conditions at higher return periods;
- modifying the ReFH model structure depending on return period.
\( C_{\text{ini}} \) – initial soil moisture

- V1: Where BFIHOST is high and PROPWET is low (permeable dry catchments) it is possible to obtain negative \( C_{\text{ini}} \) values.
- V2: Exponential model, two eqs. for above and below BFIHOST 0.65. Developed using both the calibration dataset and HiFlows dataset.

\[
\frac{C_{\text{ini}}}{0.5C_{\text{max}}} = a \times \exp[b \times (\text{BFIHOST} - c)]
\]
Return period: $T = 25$ years

Dataset: HiFlows-UK in Scotland – High FARL, Low URBEXT2000
Return period: $T = 250$ years
Compare ReFH V2 with statistical method

Return period: $T = 1000$ years
Treatment of urbanisation

• ReFH 1.0: urban extent of catchment used to choose between summer or winter design coefficients — applied to the catchment in its entirety

• ReFH 2.0: catchment divided into rural and urban areas, urban runoff treated as discrete entity
  – Based on published work by Kjeldsen, Miller and Packman (2013) Hydrology Research

• Configurable parameters
  – summer $C_{ini}$ (based on multiplier of winter $C_{ini}$)
  – urban $Tp$ (multiplier of rural $Tp$)
  – percentage of urban area that is impervious
  – $PR_u$ — percentage runoff from impervious areas

• Initial guidance on the sensitivity of simulation results to $C_{ini}$ and $Tp$ to be based on case study application.
Barriers to an urban model

- Increased complexity of the hydrological cycle
- Suitable parameterisation of urban effects
- Generalising specific effects for general use
- Lack of reliable data from urban areas
  - Hydrometric data
  - Catchment descriptor data

John Packman (1980) IH Report No. 63
\[ PR = \left(1 - URBAN_{50K}\right)PR_{rural} + URBAN_{50K}PR_{urban} \]
Revised loss model:
\[ PR = (1 - URBAN_{50k})PR_{rural} + URBAN_{50k} PR_{urban} \]

Link between digital land-use data and map data:
\[ URBAN_{50k} = 1.567 URBEXT_{2000} \]

Assume:
• 30% of urban area is impervious,
• 70% runoff from impervious areas

\[ PR_{urban} = 30\% PR_{imp} + 70\% PR_{rural} \]

PDM model used for losses in rural area
Modelling design flood hydrographs in catchments with mixed urban and rural land cover

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ABSTRACT

The effect of urban land cover on catchment flood response is evaluated using a lumped rainfall–runoff model to analyse flood events from selected UK catchments with mixed urban and rural land use. The present study proposes and evaluates a series of three extensions to an existing model to enable a better representation of urban effects, namely: an increase in runoff volume, reduced response time and a decrease in baseflow (resulting from decreased infiltration). Based on observed flood events from seven catchments, cross-validation methods are used to compare the predictive ability of the model variants with that of the original unmodified model. The results show that inclusion of urban effects increases the predictive ability of the model across catchments, despite large between-event variability of model performance. More detailed investigations into the relationship between model performance and individual event characteristics (antecedent soil moisture, rainfall duration, depth and intensity) did not reveal systematic inabilities of the model to reproduce certain types of events. Finally, it is demonstrated that the new extended model has the ability to simulate urban effects in accordance with the expected changes in storm runoff patterns.
ReFH product history

• Spreadsheet: simple, free
  – linear wizard-type user interface
  – supplies defaults for almost all parameters

• Full package: powerful, expensive
  – for “power-users”, dozens of configurable options
  – assumes user will want to calibrate model

• 5,000 spreadsheet downloads vs. handful of full package sales:
  – Minority demand for full package hence high price
Going forward

What do we need from ReFH v2 and beyond?

A system that

- delivers new science
- is simpler to use
- pays its way, but is more affordable for low volume users
Going forward

• Discontinue free spreadsheet April 2014
• Release improved, updated commercial package at low lease price => increase uptake
• Separate out expensive, less-used functionality into paid add-ons
• Reduce admin costs to keep price low: download delivery and web-based activation
FEH Research Programme

- Development of FEH web service to replace FEH CD-ROM:
  - To deliver new FEH13 rainfall depth-duration-frequency (DDF) model:
    - Durations from 1 hour to 8 days
    - Return periods from 2 to over 10,000 years
  - To deliver existing catchment descriptors
  - Provides easy, low per estimate cost access to wide range of users
  - Easier to maintain/update than existing CD-ROM
Example comparison of FEH13 and existing FEH DDF models

6-hour duration
1 in 200-year return period
FEH Research Programme

• Further development of ReFH/FEH statistical approaches:
  
  – Small UK catchments (< 25 km²)
    *Estimating flood peaks and hydrographs for small catchments (Phase 2) SC090031 – funded by Environment Agency*
  
  – To develop small catchment flow and hydrograph estimation techniques and collate and prepare data for operational use
  
  – To allow hydrologists and engineers to produce flood estimates for small catchments down to plot scale with less uncertainty than is currently possible

• Re-evaluate ReFH with new FEH13 rainfall DDF model
FEH Research Programme

• Flood estimation in permeable catchments:
  
  – Current, one geology fits all approach with a BFIHOST threshold of 0.65 delineating between impermeable and permeable catchments.
  
  – Differentiation between permeable geologies that exhibit non-flood years and those that do not.

• Localism – use of local data to enhance generalised model applications
Thank You