Using ‘flood-excess volume’ to assess and communicate flood-mitigation schemes

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with thanks to G. Piton[3] and J.-M. Tacnet[3]

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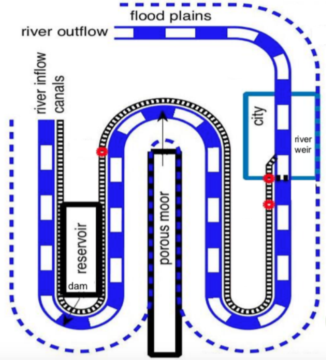
Motivation: Wetropolis

- interactive model of extreme rainfall and river flooding in an urban environment
- conceptualises many important aspects of the science of flooding and extreme events in a way that is accessible to and directly engages the public



- provides a scientific testing environment for flood modelling, control and mitigation, and data assimilation, and has inspired numerous discussions with flood practitioners and policy makers...

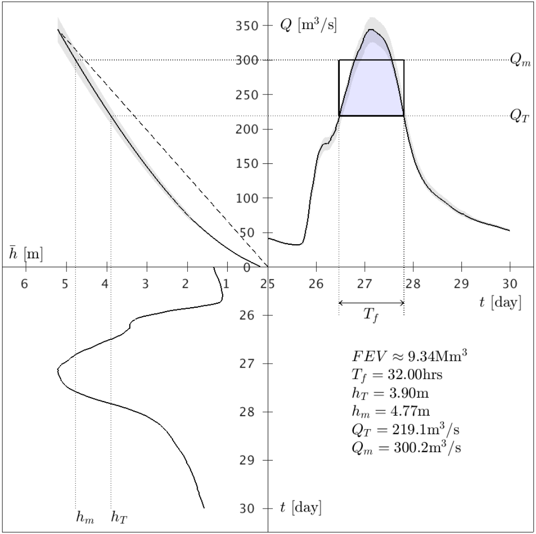
FEV: River Aire data analysis

Figure: Armley gauge data around the Boxing Day 2015 floods. Bottom left: water level time series (*raw data*); top left: rating curve (stage–discharge relationship); top right: resulting discharge time series.

Flood-excess volume (FEV):

$$V_e \approx \sum_{k=1}^{N_m} \left(Q(\bar{h}_k) - Q_T \right) \Delta t$$

... is the volume of flood water one wishes to mitigate (i.e., reduce to zero) by the cumulative effect of various flood-mitigation measures.



FEV: square lake representation

GOAL: to quantify and communicate the efficacy of various flood–mitigation measures in a straightforward and concise manner.

IDEA: calculate the FEV for a flood event of interest and express as the capacity of a 2m-deep square 'flood-excess lake' with side-lengths $\mathcal{O}(1\text{km})$.

OUTCOME: a graphical tool that (i) contextualises the magnitude of the flood relative to the river and its valley/catchment and (ii) facilitates quick and direct assessment of the contribution and value of various mitigation measures.

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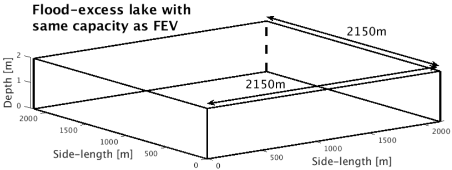
For the River Aire case: the FEV is represented as a 2m-deep 'flood-excess lake' of side-length 2.15km

$V_e \approx 9.34\text{Mm}^3 \approx (2150^2 \times 2)\text{m}^3.$



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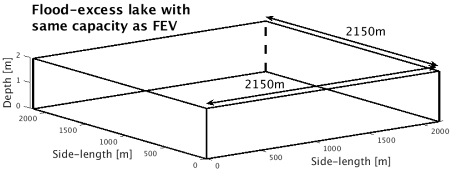
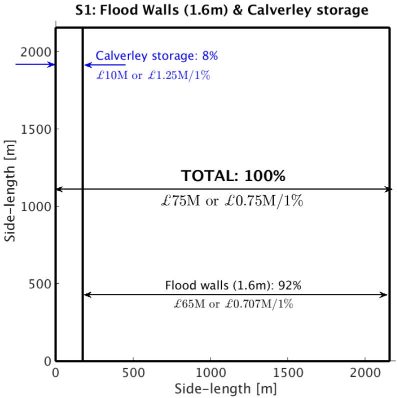
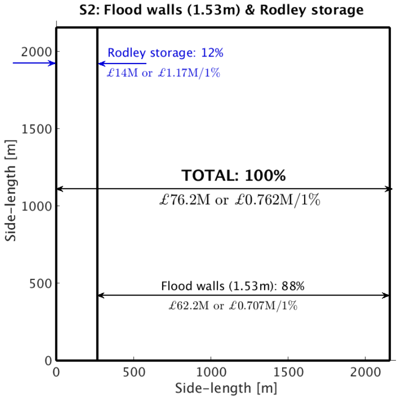


Given the size of the lake as well as the geography of the river valley concerned, one can make an estimate of the contribution and effectiveness of flood-plain enhancement for flood storage and other flood-mitigation measures.

Q: what fraction of the FEV is reduced, and at what cost, by a suite of mitigation measures?

Given a calculation (or estimate) of potential flood storage volume and associated cost of each mitigation measure, the 'flood-excess lake' can be partitioned accordingly and overlaid with a cost per 1% of FEV mitigated. E.g., two scenarios from the Leeds Flood Alleviation Scheme Two (FASII):

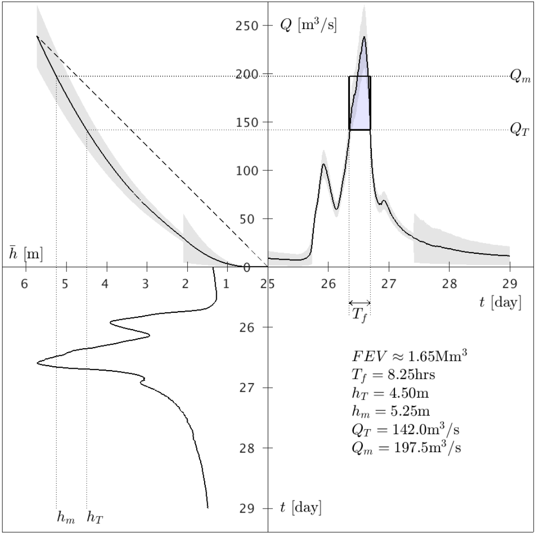




FEV: River Calder data analysis

Figure: River Calder gauge data around the Boxing day floods. Bottom left: water stage time series; top left: rating curve (stage–discharge relationship); top right: resulting discharge time series.

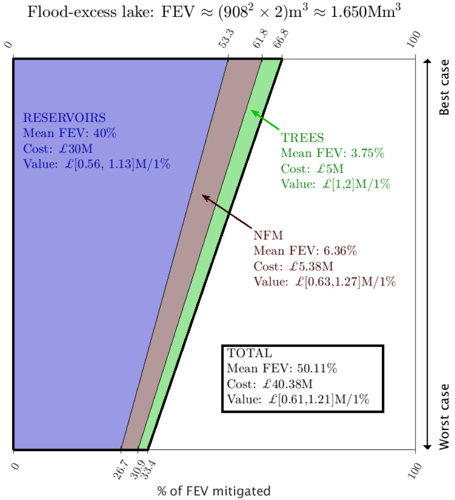
Q: what fraction of the FEV is reduced, and at what cost, by particular flood-mitigation measures?



NBS assessment: River Calder

Exploratory flood-alleviation scheme comprising (i) temporary storage in reservoirs, (ii) upscaled 'leaky' debris dams, and (iii) tree planting.

- takes into account uncertainty in storage capacity;
- draw-down and control of reservoirs has great potential;
- major upscaling of leaky dams can have a reasonable and cost-effective impact;
- mean FEV mitigated is 50%: more measures (e.g., flood walls) required to offer full protection.



FEV international: River Bragué, France

Introducing **'giving room to the river'** bed widening: increases the river width in order to increase the discharge capacity for a similar water depth.

Figure: River Bragué *reconstructed* flow data around the 2015 flash floods. Bottom left: water stage time series; top left: rating curve; top right: resulting discharge time series and FEV. New 'GRR' rating curve reduces FEV for same h_T.

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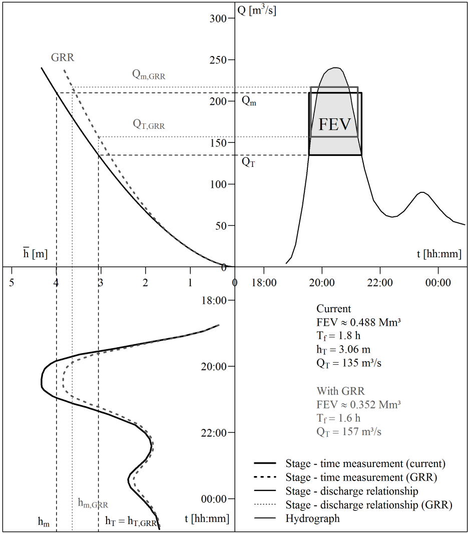
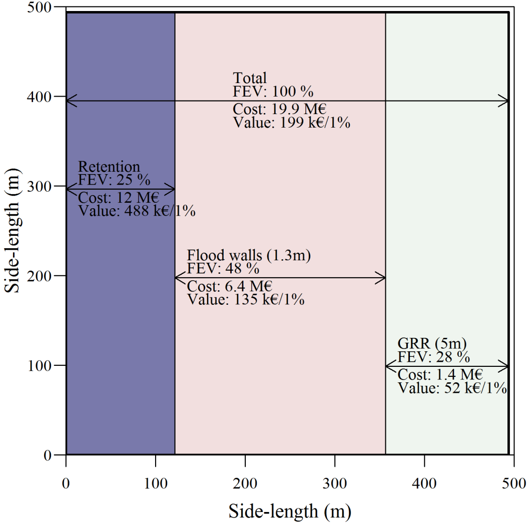


FEV assessment: River Brague

Exploratory flood-alleviation scheme comprising (i) storage in reservoirs (retention), (ii) flood walls, and (iii) GRR.

- $V_e = 0.488\ \mathrm{Mm}^3$ is represented by a 2m-deep square lake of side 494m
- lighter colour = better value
- nearly 2/3 of the 18.4M€ scheme is related to the retention measures even though they manage only 25% of the problem
- most cost-effective measure is GRR



Conclusions

The details are in some sense of secondary importance here; the **take-home message** is that the FEV analysis offers: (i) a complementary way of classifying flood events; and (ii) a protocol to optimise the assessment of mitigation schemes, including cost-effectiveness, in a comprehensible way.

Further comments:

- this analysis does not replace the need for performing detailed hydrodynamic modelling and should be used either prior to or in tandem with the modelling. It does, however, as an important practical alternative, replace such calculations in cases where insufficient computational resources are available.
- FEV enables one to quantify the contribution of NBS/NFM measures – *this is rarely done in policy/literature!* – and highlights the issue of NFM scalability.
- the square-lake representation encourages evidence-based decision-making for assessing flood-mitigation schemes.

Note: more case studies available (Rivers Don in Yorkshire and Tamar in Devon/Cornwall), and more anticipated – Japan?

Thanks very much for your attention ...

References:

1 Bokhove, O., Kent, T., Zweers, W. (2017): **'Wetropolis' flood demonstrator.** *Outreach project report, Maths Foresees.*

Available at: http://www1.maths.leeds.ac.uk/mathsforesees/projects.html

2 O. Bokhove, M. Kelmanson, T. Kent (2018a): **On using flood-excess volume in flood mitigation, exemplified for the River Aire Boxing Day Flood of 2015.** *Subm. evidence-synthesis article: Proc. Roy. Soc. A.*

See also: https://eartharxiv.org/stc7r/

3 O. Bokhove, M. Kelmanson, T. Kent, G. Piton, J.-M. Tacnet (2018b): **Communicating nature-based solutions using flood-excess volume for three UK and French river floods.** *Subm. evidence-synthesis article: Proc. Roy. Soc. A.*

See also the preliminary version on: https://eartharxiv.org/87z6w/

4 O. Bokhove, M. Kelmanson, T. Kent (2018c): **Using flood-excess volume in flood mitigation to show that upscaling beaver dams for protection against extreme floods proves unrealistic.** *Subm. evidence-synthesis article: Proc. Roy. Soc. A.*

See also: https://eartharxiv.org/w9evx/

FEV: River Don data analysis

Motivated by the Boxing day 2015 floods... *flood excess volume (FEV)* is defined as the volume of flood water one wishes to mitigate (i.e., reduce to zero) by the cumulative effect of various flood-mitigation measures.

Right: River Don gauge data around the Boxing day floods. Bottom left: water stage time series; top left: rating curve (stage–discharge relationship); top right: resulting discharge time series.

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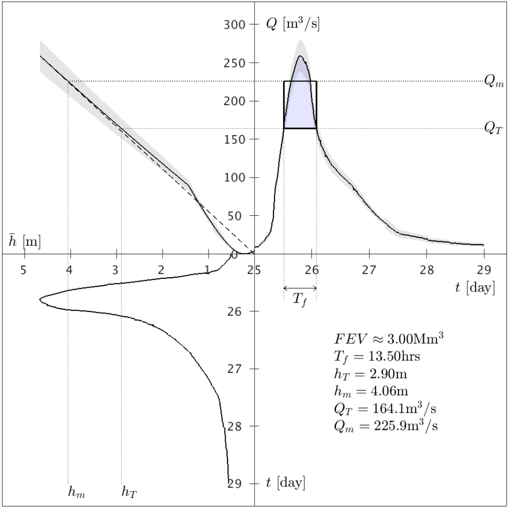
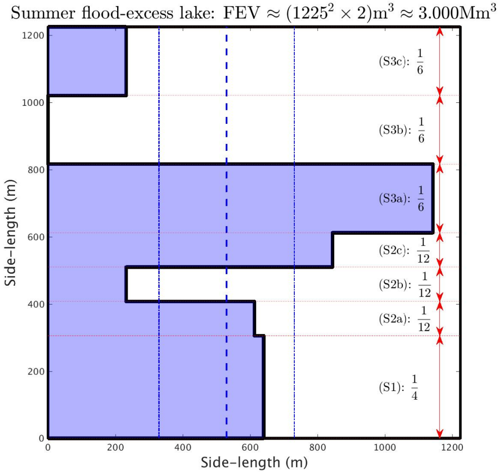


Rainfall scenarios: River Don

Graphical overview of the fraction of the FEV captured by various measures in the Don catchment for seven summer-rainfall scenarios. Stacked vertically are the respective probability distributions, relative to the associated FEV, which is fixed for all scenarios. The blue shaded areas to the left of the thick, stepped, solid line denote the fractions of the FEV mitigated per scenario, to be read horizontally (*e.g.*, 93.3% for (S3a)). The mean FEV (43.25%) over all 7 scenarios and standard deviation (16.38%) are indicated by thick and thin vertical dashed lines respectively.



Rainfall scenarios: River Don

The ‘FEV–scenarios’ framework is simple yet elegant: information covering a range of rainfall scenarios, mitigation measures, and geographical areas of a river catchment is encapsulated in a single graphic. Moreover, it is highly flexible and can incorporate any number of scenarios, rainfall distributions, and locations.

	Rainfall fraction			Probability	
Scenario	Reservoir	Sheaf	Upper Don	Winter	Summer
S1	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{4}$
S2(a)	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{8}$	$\frac{1}{12}$
S2(b)	0	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{12}$
S2(c)	$\frac{1}{2}$	0	$\frac{1}{2}$	0	$\frac{1}{12}$
S3(a)	1	0	0	$\frac{1}{12}$	$\frac{1}{6}$
S3(b)	0	1	0	$\frac{1}{12}$	$\frac{1}{6}$
S3(c)	0	0	1	$\frac{1}{12}$	$\frac{1}{6}$

Table: Summary of 7 precipitation scenarios, with rainfall fraction for the three locations, and seasonal probabilities.