Monster assimilation and adaptation in FRM: High Beck fluvial flood-mitigation case study

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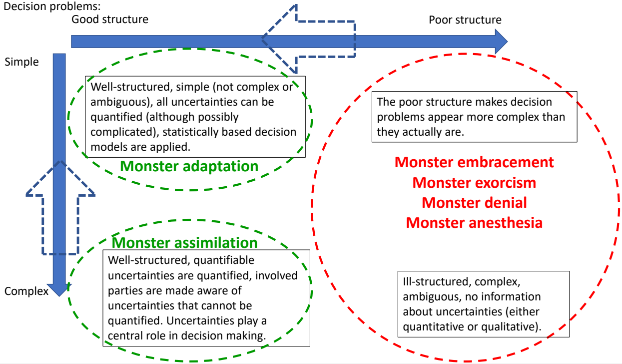

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Uncertainty monsters in Flood-Risk Management (FRM)

Knotters et al. (2024) use the monster metaphor to propose six (coping) strategies to deal with uncertainties FRM. **Monster**

- exorcism, reduce uncertainty even if it is not realisable.
- embracement, trivialization by magnifying uncertainties.
- denial, Concorde effect: limited viability yet continued investment, e.g., of some NFM (upscaling fails, e.g. using beavers) of higher-and-higher flood walls.
- anesthesia, uncertainty "prevented" by striving for consensus or agreeing about quality of information.
- adaptation, adjust uncertainty, rationalise risk mitigation & optimise chosen utility (function). UK-EA: blended approach.
- assimilation, learn from uncertainty (quantification) & accordingly make changes.

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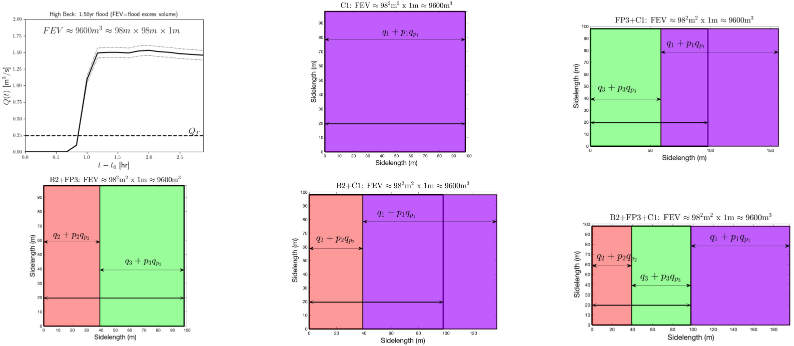
High Beck flood-mitigation case study (50yrs)

- Square-lake plots: size & costs with flood-excess volume & mitigation measures.
- Base costs q_i, probability failure p_i, repair costs q_{p_i}, $i = 1, 2, 3$; costs $q_i + p_i q_{p_i}$.
- Combine Canal C1, bund B2, flood-plain-storage FP3 into 5 scenarios:



- Utility functions: $U_1 = \sum_{j=1}^{5} w_j C_j$, $U_2 = \sum_{j=1}^{5} (w_j C_j - \sum_{k=1}^{N_j} \alpha_{kj} B_{jk})$ (co-benefits B_{jk}: e.g., droughts, extra CC, less pollution), decision tree.
- Difficult to get 9 values but U_2 yields **new insights on appreciating benefits**.

High Beck setting: mock (stylised real) case study

- High Beck is a partly culverted urban beck, circa $2000\mathrm{m}$ in length from spring to main river with a $100\mathrm{m}$ drop, it goes under and/or flows into a canal, with a culverted last $200\mathrm{m}$.
- Surface flooding occurs in neighbourhood culverts near the river at a $1\!:\!10\mathrm{yrs}$ AEP.
- New flood defence walls near river cover $1\!:\!200\mathrm{yrs}$ AEP. Then beck water trapped: limited pump action $Q_T \le 0.245\mathrm{m}^3/\mathrm{s}$.
- Surface flooding of neighbourhood culverts near river stays $1\!:\!10\mathrm{yrs}$ AEP with new flood walls.
- Canal segment for large flood storage between two locks is $7.5\mathrm{km} \times 10\mathrm{m} \times 1.5\mathrm{m}$ with several overflows.
- A combined sewer overflow (CSO) pollutes intermittently in beck; stretch from CSO to canal is $200\mathrm{m}$; extra anti-CSO-pollution measures possible.

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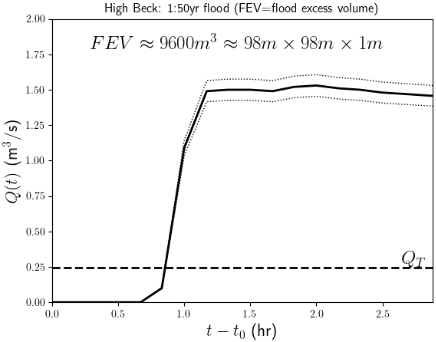
High Beck: flood-excess volume

Numerical modelling 1:50yrs High Beck flood (no field data); flood-excess-volume during event:

$$FEV = \int_{t_0}^{t_0+T} Q(t) - Q_T \, \mathrm{d}t = 9600\mathrm{m}^3 = 98 \times 98 \times 1\mathrm{m}^3 \quad \textbf{(sense of size!)}$$



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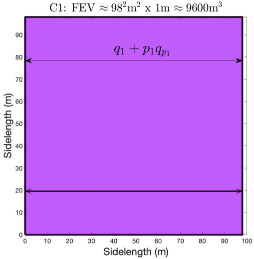
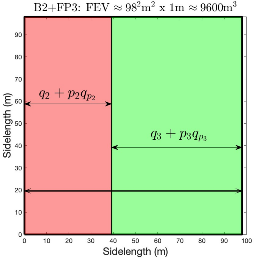
Flood-mitigation measures

Council is exploring three measures to reduce FEV (i.e., the flood damage) to zero, each with basic construction costs q_i:

- **C1**: Beck flow diverted into canal, automated gate to divide water into canal/culvert, coverage of $\alpha_1 FEV$ with $\alpha_1 > 1$, cost $q_1 + p_1 q_{p_1}$.
- **B2**: Upstream bund in flatter areas, partial prevention $\alpha_2 FEV$ with $\alpha_2 = 0.4$, cost $q_2 + p_2 q_{p_2}$.
- **FP3**: Culvert from canal to river to be opened at playing fields (protective bunds), pumping needed, partial prevention, $\alpha_3 FEV$ with $\alpha_3 = 0.6$, cost $q_3 + p_3 q_{p_3}$.





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Monster risks M1–M5

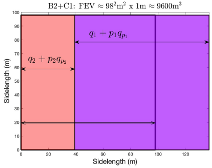
Failure probabilities p_i and damage q_{p_i}:

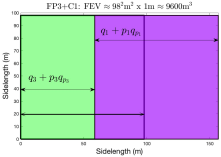
- **M1**: Fear of berm/culvert collapse of Victorian-age canal C1 (already present), costs $p_1 q_{p_1}$; fear and ignorance. Hitherto, impossible to get data or values from the "Trust" . . . (language barriers).
- **M2**: Berm collapse of bund B2 can cause flood wave on steep slopes, costs $p_2 q_{p_2}$, a priori unknown.
- **M3**: Failure of bunds in FP3 but chance low, clearing of flood debris and pollution by sewage, costs $p_3 q_{p_3}$, a priori unknown.
- **M4**: Subjective rejections and co-benefits can act as monsters and fairies. Hydrographs, probabilities and costs contain uncertainties. How do we quantify these?
- **M5**: Multi-benefit canal option may become impossible because the involved parties: i.e., Council, water company Shire and Trust (legally), do not and cannot agree on solving sewage-release, flooding, drought and ecological aspects? A case of monster anesthesia?

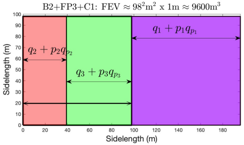
Flood-mitigation scenarios

Combinations of C1, B2 and FP3 yield the following five scenarios (over 50 yrs):

- Canal **C1**: with excess coverage.
- Bund & flood-plain storage **B2+FP3**: $1.0 \times FEV$ only and pumping needed.
- Flood-plain storage & canal **FP3+C1**: excess coverage, pumping optional depending on CSO-assessment.
- **B2+C1**: excess coverage, pumping optional depending on CSO-assessment.
- All **B2+FP3+C1**: excess coverage, pumping optional depending on CSO-assessment.
- Benefits C1: drought measure, refreshes canal, extra storage for climate change; danger: CSO spills unless CSO and beck split for $200\mathrm{m}$ from CSO to canal, extra costs $B_{11} \propto -q_{1,CSO}$.







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Discussion: good and bad decisions

What are suboptimal decisions? These are decisions that:

- lead to new problems, e.g. loss of ecological functions;
- lead to unintended consequences, e.g. high flood-defense walls lead to a false sense of security (under climate change) and can trap water inside a city; and,
- have an uneven distribution of costs and benefits when other sectors and social groups are taken into account. How does one take these into account?

Decision-taking criteria

Morgan and Henrion (1990) discuss several decision-taking criteria:

- utility-based (deterministic/probabilistic cost, cost-effectiveness, bounded cost, multi-attribute, . . .)
- rights-based (zero/bounded/constrained risk, compensation),
- technology-based using the "best available technology",
- **hybrid criteria** (combine the above), and
- an "approved process" (a suboption of a rights-based criterion) when a decision is acceptable when a specified set of procedures is met (for which decision analysis is inappropriate or pointless). Are approved processes common, in which one can hide issues behind set procedures?

Base costs, probabilities and damage costs

i: Measure	Base cost q_i (k£)	Probability p_i (/50yrs)	Damage q_{p_i} (k£)	Total (k£)
1: **C1**	500(900)	1	70	570(970)
2: **B2**	385	0.25	200	435
3: **FP3**	400	0.05	200	410
B2+FP3	-	-	-	845

Table: To obtain estimate for q_{p_1}, start from £$1.7\mathrm{M}$ repair costs of culvert breach, emptying 60km of the Leeds-Liverpool canal (2021-2022). Since canal stretch involved in C1 is $7\mathrm{km}$ $1/8^{\mathrm{th}}$ of those costs are involved so circa £210k, of which £140k are standard costs occurring in absence of flood storage in canal, so neec £70k as extra investment. Bases cost C1 are £500k plus extra £140k costs for optional $200\mathrm{m}$ pipeline to separate the CSO from beck. Except for real $q_2 + q_3 =$£785k figure, all other costs made up pending ongoing investigations. (https://www.newcivilengineer.com/latest/work-begins-on-1-7m-scheme-to-repair-breached-leeds-liverpool-canal-18-01-2022/)

Utility functions, assigning values, uncertainty

- The costs for the five scenarios are (using values of Table): **C1**: £570k (£970k with CSO-clean-up); **B2+FP3**: £845k; **B2+C1**: £1005k (1405k£); **FP3+C1**: £980 (£1380k); **B2+FP3+C1**: £1405k (£1805k).
- Take $B_{11} = -q_{1CSO}$ (less or no pollution in beck/canal); $B_{12} = q_{1cc}$ (extra climate-change flood-plain storage); $B_{13} = q_{1D}$ (drought benefits beck flow into canal); $B_{14} = q_{1E}$ (ecological value beck water into canal); $B_{15} = q_{1clean}$ (clean beck and canal).
- Using utility function $U_1 = \sum_{j=1}^{5} w_j C_j$ the optimal weights for minimal costs are:
  (a) $w_1 = 1$ and $w_2 = w_3 = w_4 = w_5 = 0$ when $\alpha_{11} = 0$ (no CSO clean-up) so **C1** will be chosen; and
  (b) $w_1 = w_3 = w_4 = w_5 = 0$, and $w_2 = 1$ when $\alpha_{11} = 1$ so **B2+FP3** will be chosen.
- Using utility function $U_2 = \sum_{j=1}^{5} w_j C_j - \sum_{k=1}^{N_j} \alpha_{jk} B_{jk}$, the optimisation depends on B_{jk} and the weight/cost combinations $\alpha_{jk} B_{jk}$ (i.e. value judgements over 50yrs).
- What values should be assigned? How do we optimise U_2?
- Example: take $q_{1CSO} = 400k, q_{1k} = 50k$ (i.e. 1k/yr each) for $i = 2, \ldots, 5$ and $\alpha_{1k} = 1$ then **C1** wins.
- Moreover, all these values will have uncertainties?

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Conclusion: utility functions High Beck

The emerging new insight using the straightforward utility function U_2 is as follows:

- The difference in costs between **C1** (canal as flood storage with CSO-beck separation) and **B2+FP3** (up- and downstream bunds and storage) is $D =$£$135k$.
- When we by choice are willing to assign the threshold value $D =$£$135k$ to those combined **C1** benefits (i.e. extra storage to deal with climate change efects, anti-drought measure, ecological effects and cleaner beck) over 50 years (i.e. £$2.7k$ annually), then the two options have equal costs or value.
- When we by choice are willing to assign more than $D =$£$1235k$ to those combined benefits over 50 years, then option **C1** is best.
- That is just over £$2.5k$ annually, which translation to annual costs makes the choice comprehensible (and pallatable).
- Alternatively, find (more than) £$125k$ of savings in the new flood-mitigation plans for the main river without sacrificing protection (possible).

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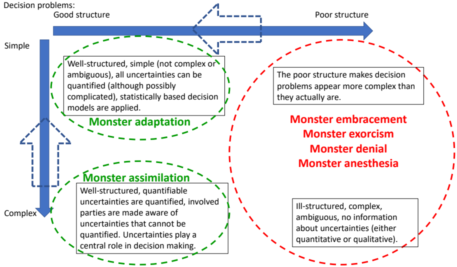
Discussion

- **Monster assimilation and adaptation** are required to create decision problems that are sufficiently simple and well-structured.
- The High Beck case study exemplifies such adaptation through the **square-lake cost-effectiveness analysis**.
- However, acquisition of a minimal, apt amount of probabilities and costs and definition of *comprehensible utility functions* remains a **open quest**.
- Ultimately, simplicity and a good structure need to be maintained to allow comprehension by the decision makers beyond taking (engineering) advice **based on faith/procedures as may often be the case in an approved process**.
- Utility function U_2 yields valuable new insights . . .



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Thank you!

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- Leeds' EPSRC Centre for Doctoral Training (CDT) in Future Fluid Dynamics offers a four-year integrated MSc with PhD programme.
- Please inquire; see `https://fluid-dynamics.leeds.ac.uk/`

Info-gap assessment of cost-effectiveness for flood-mitigation scenarios: Haigh Beck case study

Info-gap theory (Ben-Haim, 2019), consisting of three components:

- Costs $\tilde{U}_1 = C_1 + p_1 q_{p_1} + \alpha_{11} q_{1CSO} - \alpha_1 B_1$, $\tilde{U}_2 = C_2 + p_2 q_{p_2} + p_3 q_{p_3}$ (all benefits combined into B_1, here $\alpha_{11} = 1; \alpha_1 = 1$) i.e., the system's model for the two scenarios C1 and B2+FP3:
- Performance requirements $m_i(h) \le C_s$ costs and uncertainty model $I_1(h), I_2(h)$ for scenarios C1 and B2+FP3:

$$m_1(h) = \tilde{U}_1 - \alpha_1 h s_1 \le C_s, \quad \tilde{U}_1 = C_1 + p_1 q_{p_1} + \alpha_{11} q_{1CSO} \tag{1a}$$

$$m_2(h) = \tilde{U}_2 + h s_2 \le C_s, \quad \tilde{U}_2 = C_2 + p_2 q_{p_2} + p_3 q_{p_3} \tag{1b}$$

$$I_1(h) = \frac{|B_1|}{s_1} \le h, \quad I_2(h) = \frac{|U_2 - \tilde{U}_2|}{s_2} \le h \tag{1c}$$

  with dimensional s_1, s_2 in £.
- Performance aspiration or opportuneness $\tilde{U}_2 - \beta s_2 \le C_w$, $\tilde{U}_1 + \alpha_1 \beta s_1 \le C_w$.

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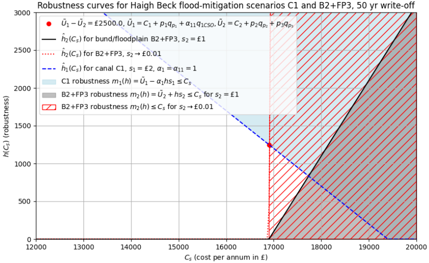
Info-gap assessment of cost-effectiveness

- Hence, for the two scenarios C1 and B2+FP3, robustness $h(C_s)$ becomes:

$$h(C_s) = \frac{(\tilde{U}_1 - C_s)}{\alpha_1 s_1} \geq 0, \quad h(C_s) = \frac{(C_s - \tilde{U}_2)}{s_2} \leq 0 \tag{2}$$

- Performance robustness or opportuneness for C1 depends on viewpoint taken on $-\alpha_1 B_1$-term.



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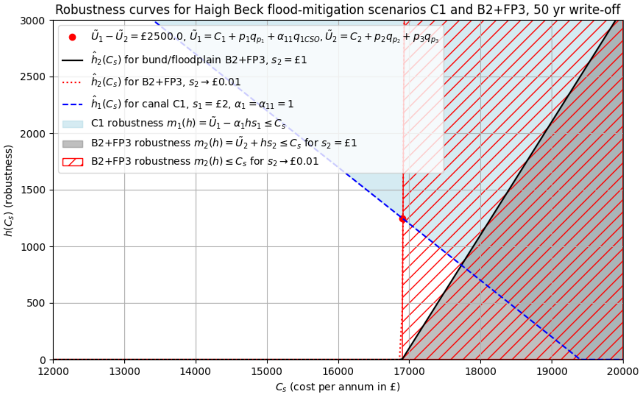
Info-gap assessment of cost-effectiveness

- C1 has unvalued (natural and other) co-benefits but its base costs are higher than B2+FP3 (starting point of lines at h=0). But C1 can be more robust than B2+FP3. For the well-known costs of B2+FP3, such that $s_2 \to 0$, the red dot is the cross-over of robustness for the two scenarios.



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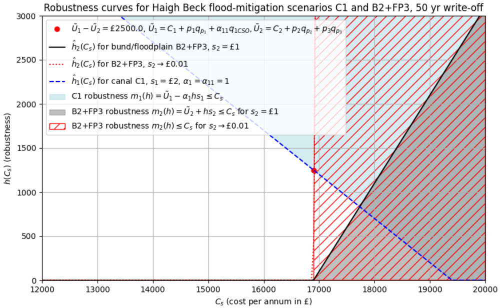
Info-gap assessment of cost-effectiveness

- The red dot at cross-over sets a value of £2500 per annum, quantifying the unvalued co-benefits. Essentially, the decision-makers have to decide whether these extra costs of 2500 are worth the money for the extra co-benefits. One of the benefits is extra capacity if the flood is more severe than the design flood. That should then lead to damage costs for B2+FP3 which I have not (yet) factored in, tilting the balance to C1 more in raising costs for B2+FP3.



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Thanks very much for your attention ...

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