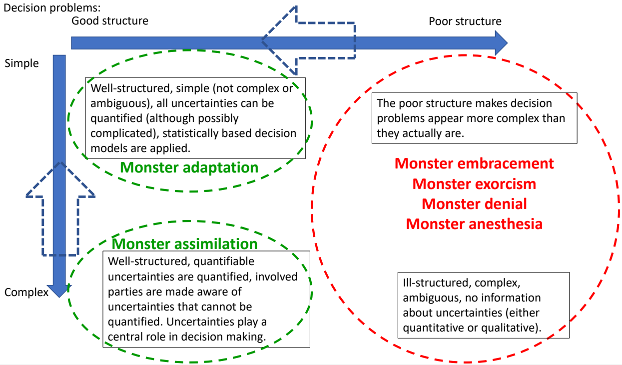
Monster assimilation and adaptation in FRM: High Beck fluvial flood-mitigation case study

Onno Bokhove [Leeds Inst. Fluid Dynamics, UK] EGU-2024, Vienna, EU



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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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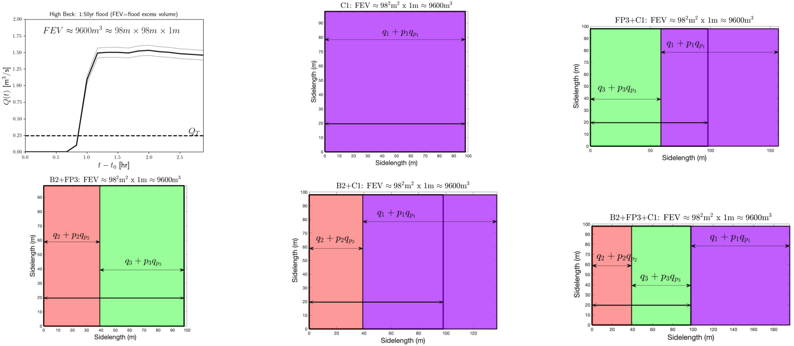
High Beck flood-mitigation case study (50yrs)

- 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: communication & visualisation (uncertainty) needed!

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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 $Q_T \leq 0.245\mathrm{m}^3/\mathrm{s}$.
- 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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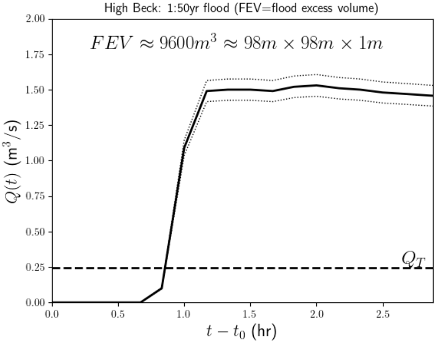
High Beck: flood-excess volume

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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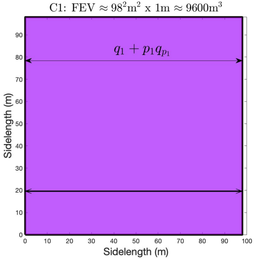
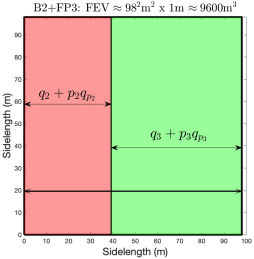
Flood-mitigation measures

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

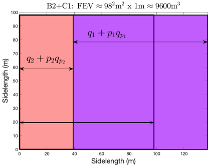
Failure probabilities p_i and damage q_{p_i}:

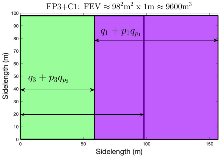
- **M1**: Fear of berm/culvert collapse of Victorian-age canal C1 (already present), costs $p_1 q_{p_1}$; fear and ignorance. Hitherto, impossible to get data or values from the "Trust" ... (language barriers).
- **M2**: Berm collapse of bund B2 can cause flood wave on steep slopes, costs $p_2 q_{p_2}$, 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?

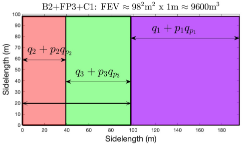
Flood-mitigation scenarios

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

- Canal **C1**: with excess coverage.
- Bund & canal **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?

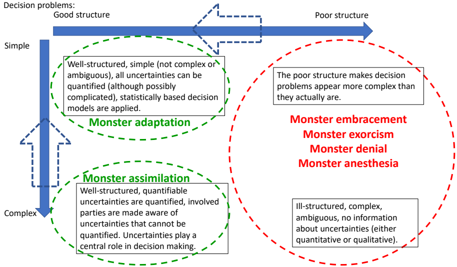
Decision-taking criteria

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?

Conclusions

- **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, the acquisition of a minimal yet apt amount of probabilities and costs as well as the definition of *comprehensible utility functions* remains a **considerable and 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**.



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Appendix: values

Measure	q_i (k£)	p_i (/50yrs)	q_{p_i} (k£)
C1	500 (900)	1	70
B2	385	0.25	200
FP3	400	0.05	200

Table: To obtain an estimate for q_1, we start from the £$1.7\mathrm{M}$ repair costs of a culvert breach, emptying 60km of the Leeds-Liverpool canal (2021-2022). Since the canal stretch involved in FP3 is $7\mathrm{km}$ $1/8^{\mathrm{th}}$ of those costs are involved so circa £210.000, of which £140.000 are standard costs occurring even in the absence of flood storage in the canal and £70.000 as extra investment. The latter costs are put forward. The base cost for C1 are £500.000 plus extra costs for the optional 200m pipeline to separate the CSO from the beck. In that case FP3 could be excluded to avoid pollution of the playing fields. Except for the $q_2 + q_3 =$£785.172 figure given all other costs are 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/`)

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Appendix: 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**: £835k; **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 $q_{11} = 0$ (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 $q_{11} = 1$ 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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