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

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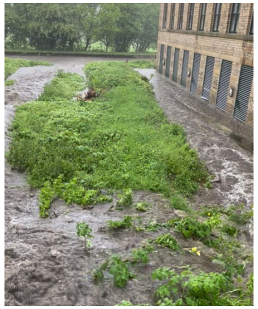
Sharing is encouraged

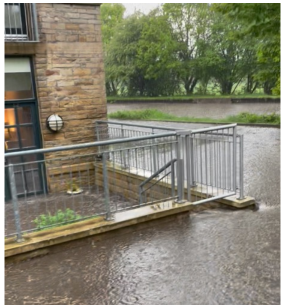
Haigh Beck & graphical cost-effectiveness tool

Goal:** value unvalued co-benefits Nature-Based Solutions (NBS)!* Case study: Urban ***Haigh Beck runs 2000m from spring to River Aire with 100m drop, flows into/under canal. Surface flooding in neighborhoods near river & canal at ~1:15yrs AEP. New flood defense walls near river cover 1:200yrs AEP but trap beck: limited pump action Q_T=0.245m^3/s. Canal segment for large flood storage between locks is 7.5kmx10mx1.5m with several overflows. Combined Sewer Overflow (CSO) pollutes beck.

Flooding, polluted, 06-05-2024 of 6 Bradford apartments (~1:15yrs AEP):



Haigh Beck-canal-Dyehouse Mill
https://www.youtube.com/shorts/T9mH2MQkA3s



canal-apartments of Mill
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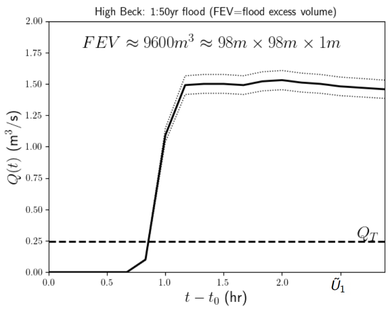
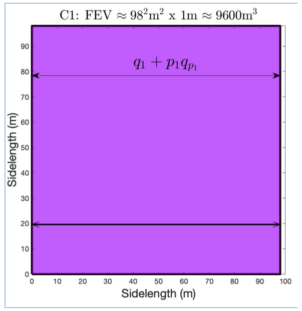
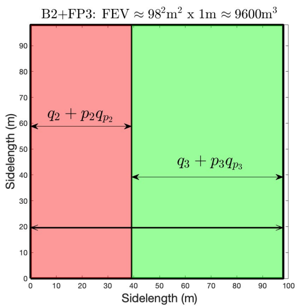






Flood-mitigation scenarios shown in square-lake graphs [1,2,3,4]:
C1 *canal*: beck diverted into canal, automated gate to divide water into canal/culvert, coverage of αxFEV with α>1, costs q_1+p_1 q_{p1}, excess FEV coverage. Benefits **N**ature-**B**ased **S**olutions: anti-drought, clean canal, extra storage for climate change; split CSO spills from beck to limit/cut **C**ombined **S**ewer **O**verflows; extra costs: -B_{11}=q_{1CSO}.
B2+FP3 *bund & flood-plain storage*: 1.0xFEV. **B2** *upstream bund*: in flatter areas, partial prevention α_2xFEV with α_2=0.4, costs q_2+p_2 q_{p2}. **FP3** culvert from canal to river opened at playing fields (protective flood plains), pumping needed, partial prevention α_3 xFEV with α_3=0.6, costs q_3+p_3 q_{p3}.

Flood—Excess Volume (FEV) is volume that causes damage [1]; ~numerical modelling (LCC/BMDC) 1:50yrs Haigh Beck flood:
FEV = $\int_{t_0}^{t_0+T}$ Q(t)−QT dt= 9600m^3 = 98x98x1m^3 sense of size!

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

Base costs, probabilities & damage costs:
To obtain estimate for q_{p1}, start from £1.7M repair costs of a culvert breach, emptying 60km of the Leeds-Liverpool canal (2021-2022 CRT). Since the canal stretch involved in C1 is 7km, 1/8 of those costs are involved so ~£210k, of which £140k are standard costs occurring even in the absence of flood storage in the canal, so £70k extra investment. Base costs: C1 q_1= £500k, plus extra costs for (optional) 200m pipeline to separate CSO from beck £400k (clean-up). ***Actual figures difficult to obtain in real cases*** (~10xFOIs!), q_2+q_3=785k given; other figures estimated, e.g., q_{p2}=q_{p3}= £200k, see Table above.

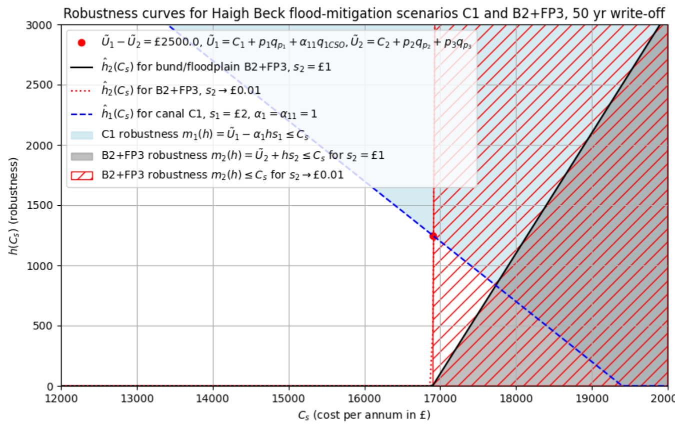
Utility functions u_1 and u_2:
$u_1 = \sum_{j=1}^{2} w_j C_j$ without co-benefits, weights w_j=0,1. **B2+FP3** best.
$u_2 = \sum_{j=1}^{2} w_j C_j - \sum_{k=1}^{N_j} a_{jk} B_{jk}$ with co-benefits B_{jk}, B_{2k}=0, N_1=5.
Take B_{11} = - q_{1CSO} = £ *400k* (no pollution beck/clean canal).
But value benefits unknown: B_{12}= q_{1cc} (extra climate-change canal storage); B_{13}= q_{1D} (drought benefits beck flow into canal); B_{14} = q_{1E} (ecological value beck water in canal); B_{15}= q_{1clean} (clean beck & canal). Difference *D*= £ *125k* costs C1 (w. CSO) - (B2+FP3). When we are willing to assign combined benefits $B_1=\sum_{k=2}^{N_1} B_{1k} > D$ in 50yrs, scenario **C1** becomes best: *break-even* £ 2.5k p/a.

Info-gap theory values NBS co-benefits!

Info-gap decision theory (Ben-Haim [5]) consists of three components:
(i) Costs $\tilde{U}_1 = C_1 + p_1 q_{p_1} + \alpha_{11} q_{1CSO} - \alpha_1 B_1$, $\tilde{U}_2 = C_2 + p_2 q_{p_2} + p_3 q_{p_3}$ benefits combined into B_1, α_{11}= α_1=1, i.e., models U_1, U_2 for scenarios C1 and B2+FP3.
(ii) Performance requirements costs $m_i(h) < C_s$, costs & uncertainty models $I_1(h)$, $I_2(h)$ for C1, B2+FP3:

$$m_1(h) = \tilde{U}_1 - \alpha_1 h s_1 \le C_s, \quad \tilde{U}_1 = C_1 + p_1 q_{p_1} + \alpha_{11} q_{1CSO}$$
$$m_2(h) = \tilde{U}_2 + h s_2 \le C_s, \quad \tilde{U}_2 = C_2 + p_2 q_{p_2} + p_3 q_{p_3}$$
$$I_1(h) = \frac{|B_1|}{s_1} \le h, \quad I_2(h) = \frac{|U_2 - \tilde{U}_2|}{s_2} \le h$$

Robustness becomes: $h(C_s) = \dfrac{(\tilde{U}_1 - C_s)}{\alpha_1 s_1} \ge 0, \quad h(C_s) = \dfrac{(C_s - \tilde{U}_2)}{s_2} \le 0$ (graph below).
(iii) Performance aspiration or opportuneness [5,6]. (U_1, U_2 models, estimates with tildes.)



Discussion: C1 has factually **unvalued** co-benefits but costs higher than those of B2+FP3 (starting point of lines at h=0). For known costs of B2+FP3 such that $s_2 \to 0$, red dot at cross-over sets value of £2.5k p/a, ***quantifying co-benefits***. C1 can be more robust than B2+FP3. Decision-makers decide whether co-benefits worth extra money. ***Critique:*** Info-gap vs. Bayesian analysis? ***Outcome:*** ***unvalued NBS benefits can be valued robustly!***

References

[1] Bokhove, Kent, Kelmanson, Piton, Tacnet 2020: *Water* **12**. https://doi.org/10.3390/w12030652
[2] Bokhove, Kelmanson, Kent, Hicks 2021: REF2021 Impact Case Study. https://results2021.ref.ac.uk/impact/0ad7c1be-8e91-4aac-ab57-6c1e873cd3f1?page=1
[3] Bokhove 2024: LMS recorded talk (our tool catches errors!): https://www.youtube.com/watch?v=RKVoV3y5ImE
[4] Knotters, Bokhove, Lamb, Poortvliet 2024: *Cambridge Prisms: Water* **2:e6**. https://doi.org/10.1017/wat.2024.4
[5] Ben-Haim 2019: Info-Gap Decision Theory (IG). In: Decision making under deep uncertainty. https://doi.org/10.1017/wat.2024.4
[6] Bokhove 2025: Info-gap assessment. Slides: https://obokhove.github.io/EGUBokhoveVienna2025.pdf