Supporting Information

Assessing the Value of Information in Contaminated-Sediment Management to Improve Decision Confidence

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Summary

The number of pages: 6
The number of figures: 3
The number of tables: 1

PROMETHEE II outranking method– Preference function and net flow calculation

The PROMETHEE II outranking MCDA method ranks alternatives based on their calculated net flow, which is a measure of relative dominance over the other alternatives. A preference function, $P_j(k,a)$, makes pairwise comparisons between the performance scores of all alternatives to establish relative dominance between each pair of alternatives on each criterion. Let the variables x_{jk} and x_{ja} denote the performance scores of remedial alternative k and remedial alternative a, respectively, on criterion j. Single alternative dominance scores are assigned based on the following linear preference function:

$$P_j(k,a) = \begin{cases} 0 \; if \; x_{jk} - x_{ja} \leq 0 \\ \frac{d}{p} \; if \; 0 < x_{jk} - x_{ja} \leq p \\ 1 \; if \; x_{jk} - x_{ja} > p \end{cases} \qquad \forall k, a \in A, k \neq a$$

if scores on j are to be maximized, and

$$P_j(k,a) = \begin{cases} 0 \; if \; x_{jk} - x_{ja} \geq 0 \\ \frac{d}{p} \; if \; -p \leq x_{jk} - x_{ja} < 0 \\ 1 \; if \; x_{jk} - x_{ja} < -p \end{cases} \qquad \forall k, a \in A, k \neq a$$

if scores on j are to be minimized.

Here, the threshold of strict preference, p, is the minimum distance between performance scores considered sufficient enough to merit a full preference (a score of 1). When the difference in performance scores is less than the threshold of strict preference, partial preference is linearly assigned proportional to the distance between performance scores (Figure S1). In this paper, p is set to 10% of the range (difference between the maximum and the minimum values) of scores for each criterion. Other preference functions are possible.

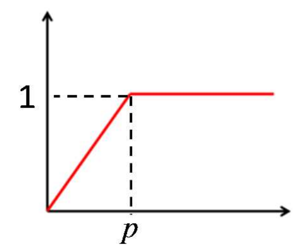


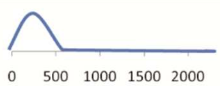
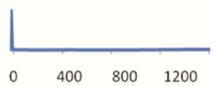
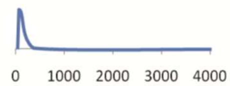
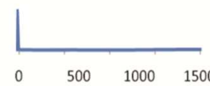
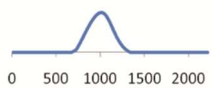
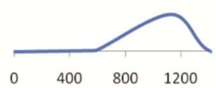
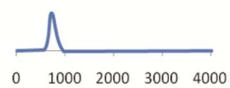
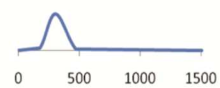
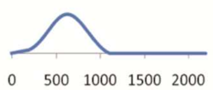
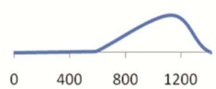
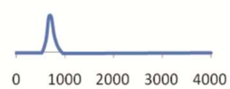
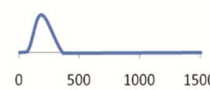
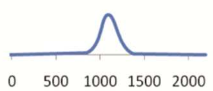
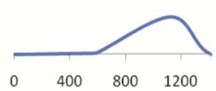
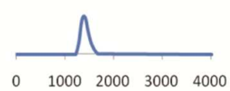
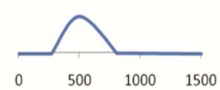
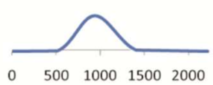
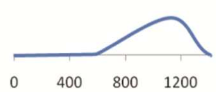
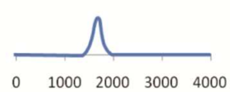
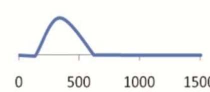
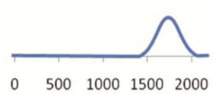
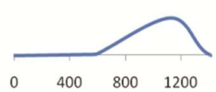
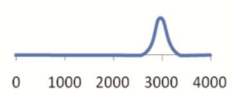
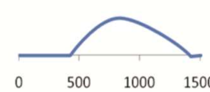
Figure S1. The PROMETHEE II outranking MCDA preference function, $P_j(k,a)$, indicates the relative dominance of alternative k over alternative a on criterion j. Here, the *x-axis* measures difference in performance scores between the two alternatives, the *y-axis* represents preferences associated with those differences, and p is the threshold of strict preference.

Description of key data from the Grenland fjord stochastic MCDA remediation study

Industrial activity over the past century in the Grenland area of southern Norway has resulted in highly contaminated marine sediments within the Grenland fjord system. Inputs of dibenzo-p-dioxins and dibenzofurans from a magnesium plant operating from 1951-2002 in the innermost section of the fjord system have resulted in significant human and ecological health risk throughout the fjord system. In the mid 1970s, plant emissions directly to seawater reached approximately 10 kg of 2378-TCDD toxicity equivalents before cleaning devices were installed in the mid 1970s and late 1980s which reduced the input to a less than 10 g per year. Though the plant shut down in 2002, significant health risks remain as the dioxins are highly persistent and tend to accumulate in marine biota. The Norwegian Food Safety Authority has issued dietary advisories to the public warning against consumption of seafood harvested in the area. A number of thin layer sediment capping options over different areas within the fjords are being considered to reduce contaminant exposure to the point where the government can ultimately remove the fish and shellfish consumption bans. Five area capping options, in addition to natural recovery, are under consideration for the Grenland fjord system, which is split into inner and outer fjords by the shallow Brevik Sill.

In the SBBL stochastic MCDA, alternatives were compared based on their performance on four main criteria: health risk reduction, socio-economic benefit expected from removing seafood health advisories, remedial cost, and estimated life cycle environmental impact. The four competing criteria were weighted differently in each of three weighting schemes meant to represent cost-effective, cost-benefit, and value-plural preferences (alternatives, criteria, and weighting schemes are described in more detail by SBBL). Because the input values for alternative performance on each decision criterion are uncertain, skewed normal distributions were used based on input data for median, 5th percentile, and 95th percentile values for the various criteria (Table 1). The PROMETHEE II MCDA algorithm was run in a 10,000 iteration Monte Carlo simulation to randomly sample values within the input distributions to calculate net flow distributions for each management alternative under each weighting scheme, given existing uncertainties.

Table S1. Health, social, environmental, and economic criteria used to preferentially asses capping alternatives for the PCDD/Fs contaminated Grenland fjord[1]. Table from Sparrevik, M.; Barton, D. N.; Bates, M. E.; Linkov, I., Use of Stochastic Multi-Criteria Decision Analysis to Support Sustainable Management of Contaminated Sediments. *Environ. Sci. Technol*. 2011, 46, (3), 1326-1334.

Alternative	Scores to be maximized		Scores to be minimized	
	Health risk reduction (y × km^2) [2]	Socio econ. benefit (NOK · 10^6) [3]	Env. impact (ecopoints) [4]	Cost (NOK · 10^6) [3]
NR				
HIFC				
HOFC				
IFC				
OFC				
WFC				

[1] The table shows distributions of alternative scores where the y-axis represents distribution frequencies (illustrative) and the x-axis shows score values in the relevant units. By using median, 5% and 95% percentile values, a triangular form of the distribution is constructed and used to numerically calculate the corresponding skewed distribution. Deterministic values are estimated as infinitely narrow distributions. See SI for more details.

[2] Area-dependent health-risk-reduction index, based on the number of years in which health risk is reduced multiplied by the area affected by this reduction. Reduction is related to a worst case scenario.

[3] All monetary values are given in Norwegian Kroner (NOK) for 2011. 1 US$=5.48 NOK (annual average exchange rate for first half of 2011).

[4] Normalized and weighted unitless value representing the life cycle impact of the alternative.

Results of the SBBL Stochastic MCDA

Results of the stochastic MCDA analysis (Figure S2), the no-additional-information case of the VoI model, indicate that, on average, HIFC should be the most preffered alternative in both the cost-effective and value-plural scenarios, while for the cost-benefit weighting scheme, the HOFC alternative is most likely to be preffered. These results are consistent with those presented in Sparrevik et al., except for minor differences (average of 7%, maximum of 13%) due to some data corrections and the addition of a strict preference threshold in this version of the model.

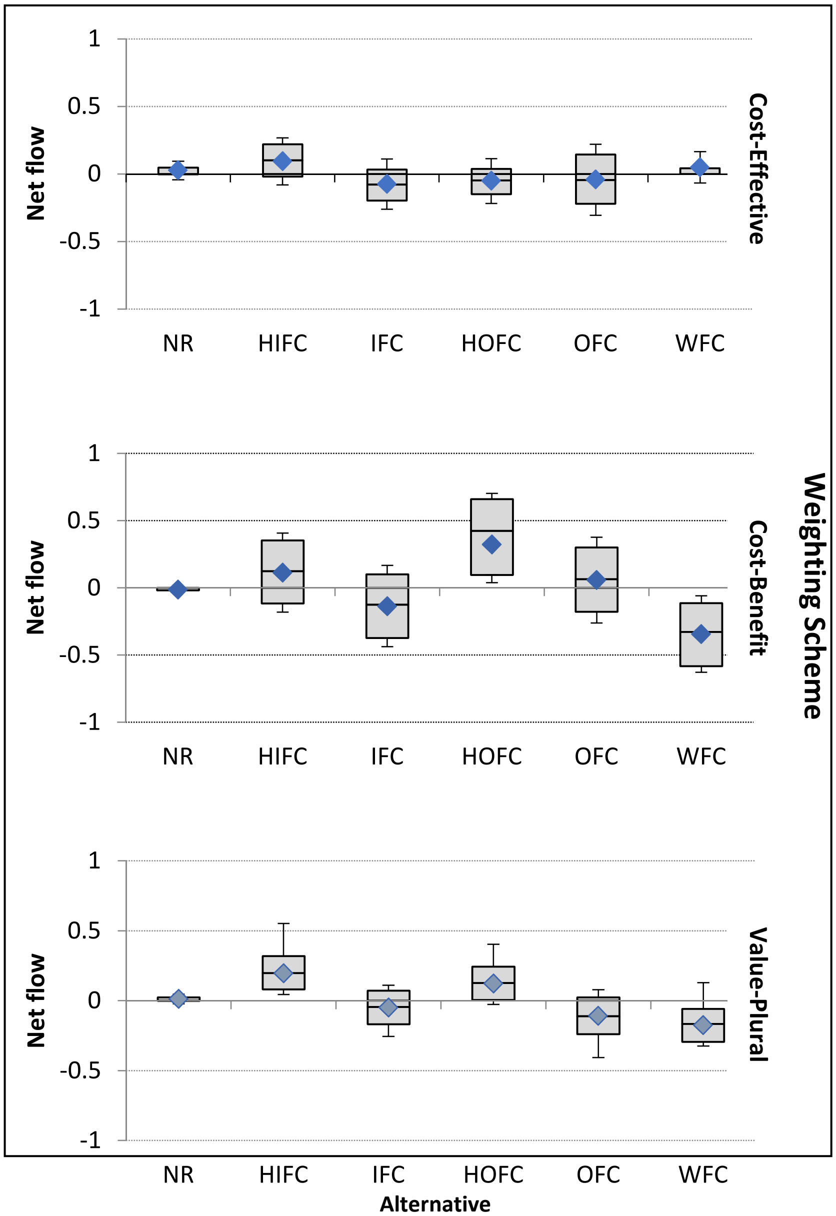


Figure S2. Plot of net flow disributions resulting from the Monte Carlo simulations of the stochastic MCDA. The grey box represents the 25th through the 75th percentile of net flow distribution alternatives, with the mean (blue diamond) and median (black line) identified. The T-bars show one standard deviation on either side of the mean. Figure updated from Sparrevik, M.; Barton, D. N.; Bates, M. E.; Linkov, I., Use of Stochastic Multi-Criteria Decision Analysis to Support Sustainable Management of Contaminated Sediments. *Environ. Sci. Technol.* 2011, 46, (3), 1326-1334 to include a threshold of strict preference of 10%.

In addition to presenting median values, percentile values are presented in Figure S3. The results expressed by lower and higher percentile values indicate that the decision makers' preferences may change based on whether they are risk averse or risk seeking (i.e., preferring the most-probable best outcome or a less-probable outcome with a higher net flow).

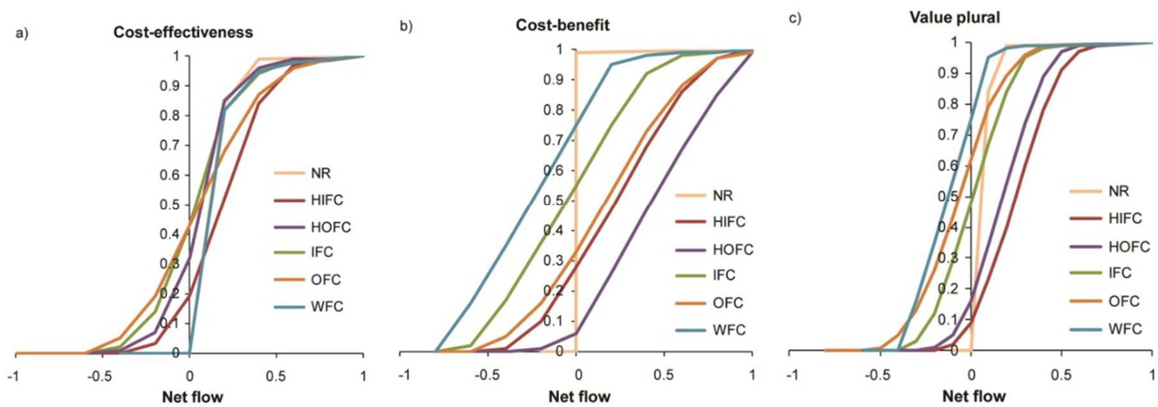


Figure S3. Cumulative distribution functions illustrating preference for each alternative with; a) cost- effectiveness; b) cost-benefit and c) value plural weighing. Right x-axes indicate high preference, whereas left x-axes indicate low preference. Figure from Sparrevik, M.; Barton, D. N.; Bates, M. E.; Linkov, I., Use of Stochastic Multi-Criteria Decision Analysis to Support Sustainable Management of Contaminated Sediments. *Environ. Sci. Technol*. 2011, 46, (3), 1326-1334.