

Using Multi-Criteria Decision Analysis (MCDA) to protect New Hampshire waterways: A case study in contaminated sediments management

by

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Introduction

Environmental issues are typically multifaceted and involve scientific, socio-political, and economic dimensions. Often the decision process can be fragmented and contentious. Both politically driven (in which powerful interests may exert disproportionate influence on the outcome) and expert-driven (in which intensively bureaucratic processes operate outside public influence) can undermine the democratic ideal of managing shared resources for the public good.

Ideally, decision regarding public water resources in New Hampshire would be made with the goals and objectives of the public in mind. However, disparate public groups are unlikely to reach consensus on which among many technological alternatives is best. Each group is likely to prefer the alternative that performs best in the areas they consider most important. Consequently, environmental problems are group decision problems from which no single best solution is likely to emerge, and multiple criteria and perspectives must be brought to bear.

Multi-criteria decision analysis (MCDA) can provide a framework for structuring complex environmental decisions. However, MCDA is a relatively new approach to decision-making in the US. To help introduce MCDA to New Hampshire, researchers at UNH conducted a hypothetical case involving management of the sediments dredged from the Cocheco River in Dover. The principal objective of this study was to investigate methods of synthesizing MCDA and expert knowledge with time and cost-effective stakeholder participation methods that could speed the introduction of beneficial reuse technologies and stakeholder-based processes into smaller, heavily resource constrained communities exemplified by the City of Dover.

Research Methods

The case study sought to ask stakeholders “What is important to you?” before asking, “Which management option would you prefer?” In this case, alternatives were hypothetical and developed exclusively by experts (with the exception of the actual alternative selected by local officials as a basis for comparison). While this exact approach may not be appropriate or successful in an actual decision process, the results of this study are expected to help test which technologies are most responsive to stakeholder concerns at this site. In practical terms, this method could be employed to prioritize different alternatives for pilot-scale study, or further research and development, and speed the introduction of new technologies into the marketplace. However, the results are site specific. That is, technological options view favorably at one site may be inappropriate for others, depending upon the views of the stakeholders involved and the specifics of the site, such as type and level of contamination, availability of beneficial end-use opportunities, or cost.

In this case, approximately 75,000 cubic yards of sediment, some of which are contaminated with polyaromatic hydrocarbons (PAHs) and heavy metals, are scheduled to be removed from

the Cocheco River in and around Dover NH beginning in the Fall of 2004. The Cocheco River is located in the southeastern part of New Hampshire and flows toward the Gulf of Maine and the Atlantic Ocean. The proposed section of the river to be dredged is that just below the dam in the center of the City of Dover to its confluence with the Piscataqua River. There are many motivations for the dredging project, including maintenance of a navigable channel, which is considered essential to the long-term economic development plans to return the City to its former status in the 19th Century as an inland port (Figure 1). Because it is a navigable waterway and thus under federal jurisdiction, the USACE has been helping the city of Dover coordinate the process and will be performing the dredging.

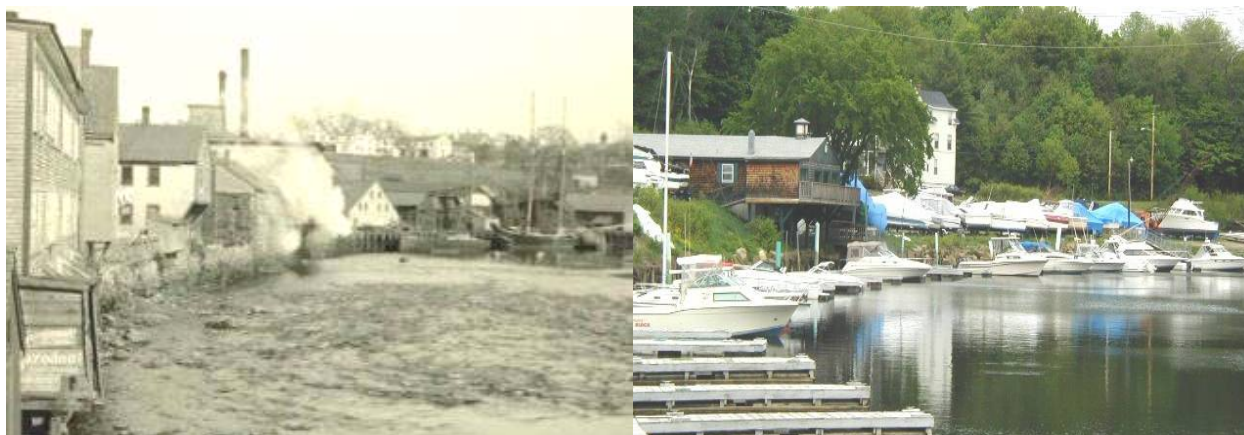


Figure 1: Dover Landing c.1890 (left) and 2001 (right). (Photos from Dover Chamber of Commerce).

There has been and still is much debate in the community over the dredging decision. However, the focus of this case study is solely on the disposal of the contaminated sediments, rather than on dredging operations themselves. In this regard the actual decision process employed by City officials was unstructured in comparison to MCDA approaches. Regulatory constraints required secure disposal of contaminated materials (i.e. prohibiting ocean dumping). Although a privately owned landfill is only 12 miles from Dover, the operators refused to accept the dredge spoils. The next largest landfill (in Maine) was prohibitively expensive due to the transportation costs and tipping fees, so secure landfill disposal was judged to be infeasible.

The next most secure option appeared to be a constructed upland disposal site. The City looked at approximately a dozen sites in close proximity to the dredging operation, but ruled out those that were presently undisturbed or not suitable for de-watering of dredged spoils (i.e. too steeply sloped). Officials felt that priority consideration should be given to sites that have already been compromised, such as the former landfill and abandoned recreation area that officials eventually chose. Nonetheless, this site required application for a waiver from NH Department of Environmental Services (NHDES).

During the process of completing dredge permit and disposal cell waiver applications; there was opportunity for public involvement in two ways: public comment on written application materials and in public hearings. Three separate applications could have initiated public comment or hearings: the USACE dredge proposal, the waiver application, and wetlands permit application. The first two generated insufficient public comment to warrant a hearing, even

though the City was required to notify abutters and plans were publicly available in several locations. However, the wetlands permit application generated significant interest. A number of questions regarding the long-term viability of the disposal site were raised, but ultimately the site was presented as the only feasible disposable alternative, and the waiver was granted. Table 1 summarizes the alternatives that were considered by the City of Dover and USACE along with the various factors that were taken into account in this determination.

Table 1: Feasibility of Disposal Alternatives

Alternative	Consideration
Turnkey Landfill	Refused to accept because of volume and characteristics of sediments
Ocean Dumping	Unacceptable because of level of contaminants
Upland Disposal Sites Along the River	Land was undisturbed (in natural state) or unsuitable (e.g. grades too steep)
Secure landfill site in Maine	Transportation costs were too high
Local Landfill (Superfund Site)	Contaminants were not suitable for this process
Former Landfill Site/ Dover Public Works	Costs of upkeep and monitoring were acceptable. Proximity to river minimizes transportation risks and costs. Officials say there will be minimal environmental effects. Others are skeptical. Waiver needed to build disposal cell.

As part of the waiver approval agreement, the City is obliged to pay for and tend to the monitoring and upkeep of the disposal cell. USACE is currently putting together an Operations and Maintenance Plan for the cell, which is part of the final approval process. The cell will be left uncapped for one year while the sediments dewater. A fence will be placed around the cell during this time to reduce the risk of public harm. The de-watering liquid will travel to the Dover wastewater treatment system, which according to hearing materials in the file, “confines the contaminants to a manageable location.” The construction of the cell will be inspected by the USACE with the city of Dover becoming the final owner of the site. Some of the disposal area is part of Maglaras Park where PAHs from the disposal of the 1985 dredging were discovered on the soccer and baseball fields. There are plans to use the new spoil site as fields again, once the cell has been capped and covered and if safety standards allow.

While the decision-making process employed by local authorities in the Cocheco project is rational, practical and may have resulted in a wise choice, from the stakeholder and MCDA perspectives, it is clear that the process was not explicitly structured to elicit or be responsive to stakeholder concerns. Additionally, the introduction of new alternatives—such as beneficial reuse technologies—would have increased the complexity of the choices so significantly that it could have overwhelmed the simplified, heuristic decision process employed. Therefore, the Cocheco River case was selected as an appropriate opportunity to test new methods of stakeholder participation that could guide researchers towards a better understanding of human concerns without the high stakes often associated with actual decision processes.

There are a number of methods of stakeholder value elicitation and public participation available to choose from. The actual methods employed in this case study rely upon a combination of

processes mentioned in the literature, considering the resource limitations of the research group. The study was designed to have three primary points of contact with stakeholders:

1. A semi-structured interview to establish the primary concerns.
2. A written survey.
3. A more structured verification interview.

Following the initial interviews, the information regarding stakeholder values was forwarded to experts for additional characterization of the decision criteria (by identifying attributes of each, and if possible, appropriate metrics for these attributes) and assessment of the performance of new technologies in the areas identified. Figure 2 shows a schematic of the methods employed while the details are described in the paragraphs below.

Case Study Research and Identifying Key Stakeholders

Research began by investigating the background information available on the local case study. Business interests, government officials, local citizens and environmental advocacy group leaders and members were identified in public documents generated during the permitting and public hearing process. Additionally, abutters to a proposed disposal site were identified, as were employees at the local wastewater treatment plant, individuals mentioned in newspaper articles, and anyone else recommended to researchers. The stakeholders fell into four general categories as detailed in the box at right.

Key Stakeholder Groups

Citizen/Environmental Advocacy Groups

Conservation Law Foundation, SaveDover, Coheco River Watershed Coalition, Dover Conservation Commission

Business Interests

Greater Dover Chamber of Commerce, George's Marina

State & Local Government/State Agencies

City of Dover Environmental Projects Office, New Hampshire Dept. of Environmental Services, Dover City Council

Local Citizens/Abutters to the Project

Individuals identified in public comment documents, or solicited from knowledge of proximity to affected areas.

Initial Interviews

Using a semi-structured, reflective interview, representatives from each stakeholder group were interviewed personally or on the phone to identify key decision criteria and project objectives. In general, semi-structured interviews have a predetermined order but still ensure flexibility in the ways issues are addressed by the subject. A sample interview centered on some of the following questions:

- What has been your level of involvement with the Coheco River Dredge and Disposal Project?
- What concerns do you have with the disposal/management options for the contaminated sediment?
- How did you participate in the decision making process? What were your perceptions of the process?

- When it comes to the management of contaminated sediments in general, what are your biggest concerns, most important values and/or guiding principles for evaluating the situation?

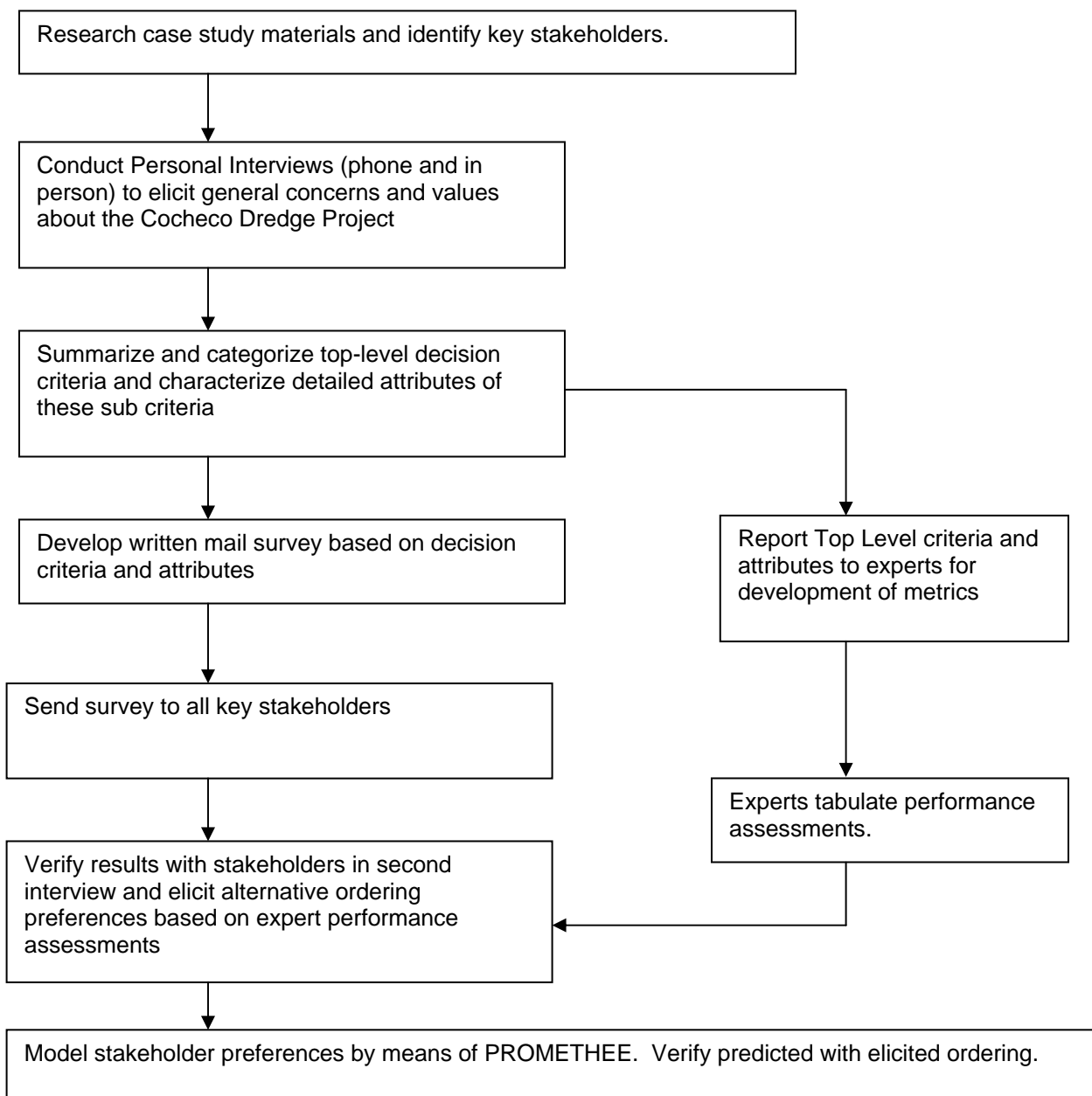


Figure 2: Schematic Representation of Stakeholder and Expert Engagement

Among the salient concerns voiced during the initial interviews were four recurring themes: economics, environmental quality, human habitat, and ecological habitat. Although stakeholders differed in emphasis, each of these qualities was mentioned during most of the interviews. At this stage, stakeholders helped to characterize the major decision criteria by discussing how they could be measured or manifested in specific attributes. For example, economics was identified as an important decision criterion, but economic considerations may have facets differing in

importance to different stakeholders. Project costs (80% of which are slated to be paid from Federal sources), maintenance costs, and community economic development (e.g., jobs) all were identified as driving the overall economic assessment. Sample responses are listed in the box below.

Sample Interview Responses to the Questions Detailed Above & Concerns Extrapolated from Public Comment

"I would accept increased costs for a better solution, especially because the whole country is bearing the cost of the project..." *This respondent was also concerned with the materials that had previously been buried in the proposed disposal site and said "there is awful stuff buried there."*

"Why would Dover want this recreational field (proposed after disposal site is covered) if there is a possibility that children might be exposed to highly carcinogenic compounds?"

"How will hotspots in the river be dealt with? Will more contaminated sediments be disposed of differently?"

"Will there be a public sign off that the cell has been constructed to approved specifications?"

"The proposed disposal site seems like the best option (even though we live 800 feet from the site), however, disposal must be done in a proper manner."

"The proposed disposal site raises serious concerns about the potential for future impacts to the aquatic environment."

"...because the dredge spoil de-watering area cover will eliminate direct contact with both the proposed and existing dredge spoil sediments that are present at the site, the city feels this outcome is more protective of public health and the environment than the existing conditions."

"Has there been groundwater testing near this site? Should children be allowed to play in areas where waste is exposed and what should the city do to make the area safer?"

"I would have liked to see a full analysis of the project consisting of a larger scope (one that would be required by an EIS) instead of just an E.A. Cost benefit analysis and other questions that would be answered with a more searching review."

"During the decision process, I felt like there were times when dissenting voices were shot down."

In general, "Environmental regulation is important but advisory needs to be tempered with the realities of life (e.g. individual property rights) and done in the most environmentally sound manner."

The reuse and cap of the disposal site and cell is a "three way win for the Department of Environmental Services and the city of Dover because it will provide: 1. A double cover for the old landfill. 2. A new cap for the old contaminated cell. 3. A new state of the art, monitored containment cell for the newly dredged material."

The Written Survey

The four top-level criteria identified in the interviews were reported to the sediment management technology expert group to define specific measurable attributes that could be incorporated into a written stakeholder survey. In many instances, the attributes identified could be interpreted as relating to more than one of the top-level decision criteria, suggesting that the criteria are not completely independent – a quality that is typical of real world environmental decision problems. Also, several of the attributes identified proved difficult to translate into measurable quantities. For example, although experts agreed that air & water quality measures could be an important aspect of how stakeholders interpret overall environmental quality, devising comprehensive

metrics for air and water that could be accurately and economically estimated and easily communicated to stakeholders proved to be challenging.

The survey was sent to 15 key stakeholders and served as a tool to qualitatively and quantitatively measure their values about the four criteria in general. The case study served as the reason for conducting the survey, which the respondents knew, but they were also encouraged to answer the questions based on their values in general. Stakeholders were asked to assign percentage weights for each of the four major decision criteria, and to rank all attributes in order of importance in several different groupings of four to eight. Attributes were compared pair-wise and ranked to determine the dominance of some over others. When one attribute was consistently preferred to another attribute in all groupings, the preferred attribute was awarded a

‘win point.’ Intransitivities (in which one attribute may be preferred over another on two questions but the order reversed in a third) were handled by awarding a partial win point (such as two-thirds for the first alternative and one-third for the second in the parenthetical example). A final ranking from 1 (most important) to 11 (least important) was established on the basis of the win points. In each case, respondent profiles emerged from the attribute rankings that were consistent with the directly elicited percentage weightings. In the end, the direct percentage weightings were sufficient to facilitate the MCDA.

3. Please rate your level of trust in the following sources of information that may help you evaluate dredged sediments management alternatives.

	Very High	High	Average	Low	Very Low	Don't know / Not sure
Non-governmental organizations	5	(4)	3	2	1	8
State agencies	5	(4)	3	2	1	8
Federal agencies	5	(4)	3	2	1	8
Local government	5	4	3	2	(1)	8
Neighbors/friends	5	4	3	(2)	1	8
Other - Specify: <i>Univ. Scientists</i>	5	4	3	2	1	8

Depends on which one of each category

The following section asks a number of similar questions. Please answer each question based on its own individual criteria.

4. Please rank the following land uses in order of importance to you in general, listing the highest priority first (1) and the lowest priority last (4).

Rank	Criteria
3	Recreation/open space
4	Building/infrastructure/commerce
2	Flood plain/shoreline (swimming, fishing)
1	plant, animal & fish habitat/health

5. Please rank the following criteria in order of importance to you in general, listing the highest priority first (1) and the lowest priority last (7).

Rank	Criteria
7	commerce
3	human health
5	availability of flood plain/shoreline for human and animal benefit
2	plant, animal & fish health
1	water & air quality
6	air and water treatment costs
4	availability of recreation/open space

by benefit - you must see below
Riparian zone health contributes to all other factors.

Humans benefit from an intact shoreline & flood-plain without necessarily using them for human activity. Consequently, healthy ecosystems must be my priority.

Figure 3: Example survey page.

independent. For example, a single attribute such as preservation of floodplain and shoreline was perceived as being a meaningful attribute of ecological and human habitat by most stakeholders, but also perceived by some as relating to environmental quality and economics. In particular, several attributes identified with “environmental quality” were also identified as

relating to other decision criteria. Figure 4 is representative of how some stakeholders mapped the attributes relative to the four top-level criteria. However, not all stakeholder (or experts) would relate the attributes to top-level criteria in exactly the same way.

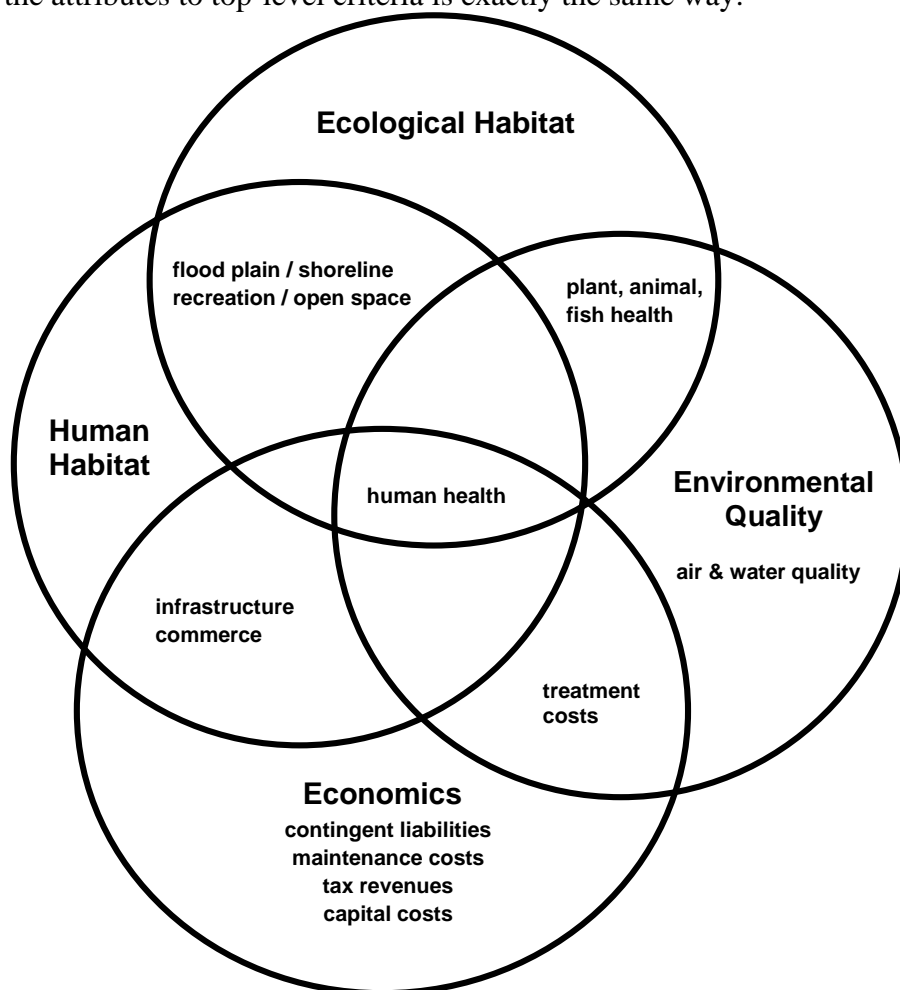


Figure 4: Typical assignment of attributes to top-level decision criteria.

Experts Tabulate Alternatives Performance Table

Graduate students and faculty at the University of New Hampshire's Center for Contaminated Sediments Research (CCSR) were interviewed about their research on innovative beneficial reuse alternatives. This expert group chose wetlands restoration, cement manufacture, and flowable concrete fill as potentially viable technologies for the Cocheco site. Interviews served as a forum to elicit assessments of these alternatives, as well as the capped cell alternative chosen by local officials, to create a performance table that compares the attributes of each alternative to the others based on the four criteria identified by stakeholders in initial interviews. The results are summarized in Table 2.

Table 2: Expert Performance Assessment of Alternatives

Alternative	Cost (\$/cy)	Environmental Quality	Ecological Habitat (acres)	Human Habitat (acres)
Cement Manufacture	\$30 <i>+3.0</i>	High <i>+2.0</i>	0 <i>-1.0</i>	0 <i>-1.0</i>
Flowable Fill	\$55 <i>+1.0, -2.0</i>	Medium <i>-2.0</i>	0 <i>-1.0</i>	0 <i>-1.0</i>
Wetlands Restoration	\$75 <i>-1.0</i>	High <i>+2.0</i>	+10 <i>+3.0</i>	0 <i>-1.0</i>
Upland Disposal Cell	\$40 <i>+2.0, -1.0</i>	Medium <i>-2.0</i>	0 <i>-1.0</i>	+4 <i>+3.0</i>

Notes: Expert assessment determined the performance of each of the four salient criteria that stakeholders' identified as important. The actual alternative planned for use in the Cocheco River Project is the Upland Disposal Cell. Dominance rankings are given in *Italics* according to the number of clearly inferior (positive) or superior (negative) alternatives.

Experts were challenged to develop metrics that could faithfully represent the diversity of stakeholder views regarding each criterion, could be assessed reliably (in the sense that different expert assessments would result in similar results), and convey meaning. For example, improvements in human habitat could be measured in terms of acres, property values, or specific functional units (such as the number of building lots or youth soccer fields), just as ecological habitat might be measured in terms of acres, or in terms of increased wildlife populations. Ideally, both experts and stakeholders would participate in devising the proper metrics to assess performance. It is even possible for analysis to continue in the event different groups use different criteria, or judge the performance of the alternatives differently against the same criteria. However, it became clear during the process that simple measures would be easier to assess, and that in most cases the differences between the technologies were so striking that the patterns of dominance would not be changed by refined metrics. In this particular case, the performance assessments must be interpreted as hypothetical--both because the technologies themselves are not fully developed and because the details of the case study are not sufficiently developed to allow for detailed assessments

In MCDA, alternatives may be judged against one another by comparing their performance on each criterion. For example, experts expected cement manufacture to be the least expensive dredged material management option—consequently outranking all three other alternatives with respect to cost. Moreover, cement manufacture is tied with wetlands restoration for the highest environmental quality assessment, with both outranking the other alternatives. Wetlands restoration dominates all the others in the creation of ecological habitat, whereas the upland capped cell dominates in human habitat—chiefly due to the plan to return use of the recreation areas following capping of the cell. It is clear from Table 2 that flowable concrete fill is inferior to one or more alternatives in all respects for this site. Based solely on this table, there would be no reason to choose this option in the case study. However, another situation might be better suited for this option.

To guard against bias among the stakeholders (in the absence of full vetting of the details of each alternative) the title of each alternative was presented to stakeholders as Option #1, Option #2, etc. and the respondents were asked to evaluate each alternative upon the merits presented in the table. Also, the performance *rankings* (+3.0, -1.0, etc.) were not included in the performance table made available to stakeholders.

Verification Interviews

Interpreted survey results were verified in a personal one-on-one interview with each stakeholder who completed the survey and was willing to participate in the interview (12 total). During this interview, stakeholders were presented with the 'win points' attribute rankings based upon analysis of the written surveys and were asked to confirm and/or revise their interpreted values as well as elaborate on their concerns pertaining to the disposal of contaminated dredged sediment in general and in particular with the Cocheco Case. They were also asked to comment on the survey method as a tool to increase public participation in the decision process. The following are sample questions asked of stakeholders during the verification process:

- How does our interpretation of your values match with what they actually are?
- What are your thoughts on the design of the survey? What were its strengths and weaknesses?
- Do you have suggestions for improvement of the survey?
- Is there anything you would like to tell us that was not captured in your survey?
- Can you please elaborate on the written comments you made on the survey?

Follow up questions were asked based on the stakeholders' responses to the above questions. Many of the stakeholders were critical of the actual survey tool, stating that it was hard to differentiate among the interrelated criteria and that they were not used to expressing their values about this type of decision. However, the majority agreed that researchers had faithfully captured their values in general and were willing to elaborate on them during the interviews. All participants were agreeable to sharing their views and appreciated being incorporated into the research process. Additionally, the interviews served as an opportunity to begin eliciting stakeholder input on the beneficial reuse technologies. At the end of each interview, stakeholders were presented with the alternative performance table, asked to make blind rankings of the four technological options, and send it back to the Center at their convenience.

Predicting Stakeholder Preferences for Management Alternatives using MCDA.

Few MCDA approaches are adaptable to group decision-making problems associated with the environment. For example, mathematically complex methods such as multi-attribute utility theory (MAUT) are especially demanding of stakeholders, who must define inter- and intra-criteria weighting functions. When the number of potential decision-makers (or stakeholders) is large, the time and effort required to elicit extensive information can be prohibitive. Moreover, a utility-maximizing approach essentially reduces the decision process to a mono-criterion objective function. These approaches are least appropriate for problems that involve criteria that are incommensurate, or alternatives that are difficult to compare (Seager 2004). For assessment of innovative technologies in particular, use of simplified MCDA methods may be required. For these reasons, multiple decision-analysis approaches may be used, recognizing that different recommendation may result from use of different MCDA tools. However, management of dredged contaminated materials is often undertaken by resource-constrained local officials on a

modest scale. Particularly when decisions are spaced decades apart in time, as in the Cocheco case, officials may be unwilling to invest in multiple decision analysis methods. In this case, a simplified outranking method may be sufficient.

In environmental problems, outranking methods have several advantages over other methods:

- Outranking methods are typically only partially compensatory. That is, massive overperformance on one criterion (such as cost) may not make up for underperformance on others (such as environmental protection).
- Stakeholder value elicitation can sometimes be simplified to direct elicitation of intercriteria weights. More sophisticated analyses can incorporate pseudo-criteria, such as indifference thresholds and partial preferences, for handling uncertainty in performance assessment or various degrees of stakeholder sensitivity (Lahdelma on psuedo criteria). However, initial analyses can proceed with basic information and results are usually easy to communicate to stakeholders (Geldermann & Zhang 2001).
- Outranking methods are tolerant of partially-quantitative information, such as ordinal criteria. This can be a significant advantage in environmental problems where fully-quantitative performance assessments are difficult or impossible to devise.
- Alternatives need not be fully ordered. In fact, outranking methods may identify alternatives that are incomparable due to qualitative differences.
- Outranking methods are capable of representing multiple views, or exploring acceptability weight spaces. That is, in the absence of intercriteria weights or reliable performance information, outranking methods are able to calculate a range of weights or performance specifications that would result in any one alternative dominating others.

Survey results in this case study were analyzed using the PROMETHEE method of pair-wise comparison embodied in *Decision Lab 2000* software (Visual Decision Inc.) In PROMETHEE, which stands for Preference Ranking Organisation METHod of Enrichment Evaluation, alternatives are compared and ranked under each decision criteria. Dominated alternatives (i.e. inferior in every respect) can be identified easily and tradeoffs identified among the remaining alternatives highlighted. Individual stakeholder orderings are established by weighting decision criteria as a percentage of the overall decision in a manner consistent with expressed stakeholder values. Dissimilar individual stakeholder preferences are never summed or averaged. Each stakeholder may have a different ordering of the preferred alternatives. Consequently, PROMETHEE is especially useful for calling attention to potential conflicts or alliances between different stakeholder groups.

In PROMETHEE, rankings are based upon calculation of positive and negative ‘flows,’ which are measures of the weighted average ranking of each alternative according the performance table. For example, in an equal-weighting (or balanced scenario), the positive flow for cement manufacture is calculated as the sum of positive rankings +3.0 (from economics), +2.0 (from environmental quality), zero, and zero (from both human and ecological habitat), divided by the total number of spaces in the matrix made up of competing alternatives (in rows) and criteria (columns), which is 12. The result is 5 divided by 12, or .42. Negative flows are computed on the basis of negative rankings. Lastly, overall comparison of positive flows, negative flows, or the sum of these may determine alternative orderings. Often, the alternative orderings provided by the positive and negative flows are identical. When they are not, PROMETHEE may have

identified alternatives that are incomparable. In this case, one alternative may exist that has both outstanding strengths and serious shortcomings. Selecting this alternative may reflect a strongly held preference for the criteria assessed as strengths -- a position that may generate controversy.

Different preferences are modeled for each stakeholder by adjusting the relative weights assigned to the decision criteria. An example ordering is shown in Figure 5, with positive flows reported in a small box above negative flows. Of the seven stakeholders that participated in the ordering of preferred alternatives, the decision analysis correctly predicted the elicited ordering of all four alternatives for three of the stakeholders. In the other four cases, the stakeholders' first and second choices matched exactly. These results suggest that the researchers can rely upon the stakeholder value elicitation instruments to communicate a reasonably well quantified expression of values that can be employed to prioritize development of the current alternatives, or screen new alternatives that may be introduced into the decision process later. Moreover, while the decision matrix in this case was fairly simple for stakeholders to analyze heuristically, the consistency between predicted and elicited results suggests that the decision analysis may be a valuable tool to assist decision-makers in evaluating more complex situations in a manner consistent with stakeholder values.

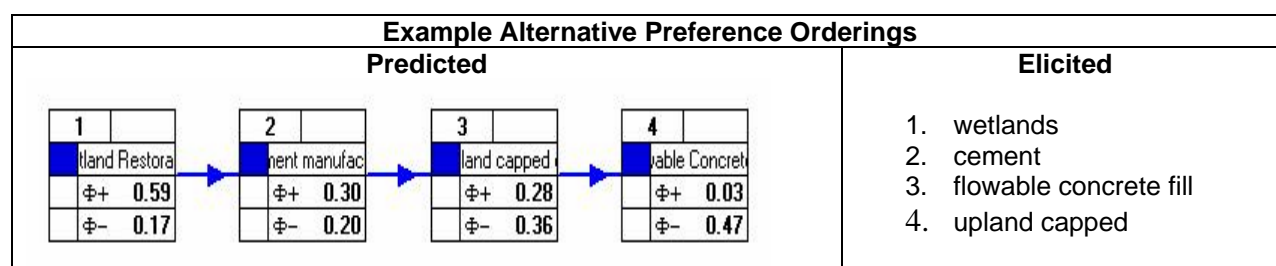


Figure 5. Based on individual preference functions, Decision Lab can predict the order in which any stakeholder would prefer available alternatives using PROMETHEE. Predicted results for all stakeholders were compared to the actual ordering of alternatives elicited from stakeholder inspection of the performance table given to stakeholders during the verification process.

Considerable uncertainties are built into both the value elicitation and performance assessment instruments. Therefore, it is important to investigate the stability of the alternative orderings—i.e., the sensitivity of the ordering to the criteria weightings. When small changes in criteria weights result in a change in preference ordering, decision makers may surmise that the preferences are weakly held, and that opportunities for compromise may exist. Alternatively, when the preference orderings are quite stable, they may be the result of strongly held views. Two or more such groups with different preferences may be in conflict.

To simplify the analysis, like-minded stakeholders were grouped into four general types according to the criteria they held to be most important. Groups most concerned with human health, eco-environment, balance, and costs emerged. The criteria weights used to represent each group are presented in Table 3, and the first two preference alternatives predicted for the group. Note that in some cases the ranking of alternatives would change subject to whether the most positive, least negative, or best combination of flows is used as the basis of the ordering. In these cases, the alternatives may not be directly comparable, and a strict preference may not be completely expressed. Also, the balanced group presents an interesting case in which two alternatives are equally preferred (in both positive and negative flows) as second best.

Table 3: Criteria Weightings of Typical Stakeholder Groups

	Human Habitat	Ecological Habitat	Env Quality	Cost	1 st Choice	2 nd Choice
Human Health (3)	0.5	0.1	0.25	0.15	Upland Cap +0.6, -0.25	Cement +0.32, -.20
Eco/Env (6)	0.2	0.3	0.4	0.1	Wetland +0.57, -0.17	Cement +0.37, -0.17
Balanced (2)	0.25	0.25	0.25	0.25	Cement +0.42, -0.17	Upland Cap +0.42, -0.33 Wetland +0.42, -0.33
Cost Group (1)	0.25	0.05	0.1	0.6	Cement +0.67, -0.10	Upland Cap +0.65, -0.28

Note: The numbers in parentheses indicate the number of respondents in each group. Positive and negative flows are separated by commas below the name of the preferred alternatives.

To investigate the possibility that one of the alternatives may emerge as a consensus choice, the strength of conviction of each group must be investigated. One approach is to estimate the minimum change in expressed criteria weighting required to effect a change in the preference ordering. This approach obviates the need to reliably and precisely establish exact criteria weights. Instead, the rankings may be interpreted more as one of many likely (or unlikely) outcomes. For example, a slight overweighting of any one criterion in the Balanced group would break the tie for second place between wetlands restoration and upland capped cell. The likelihood that, upon further reflection, the Balanced group might reconsider their views must be considered. Figure 6 presents the weightings considered representative of each group as a column chart. The stability intervals over which the first two preference orderings are stable are represented as error bars.

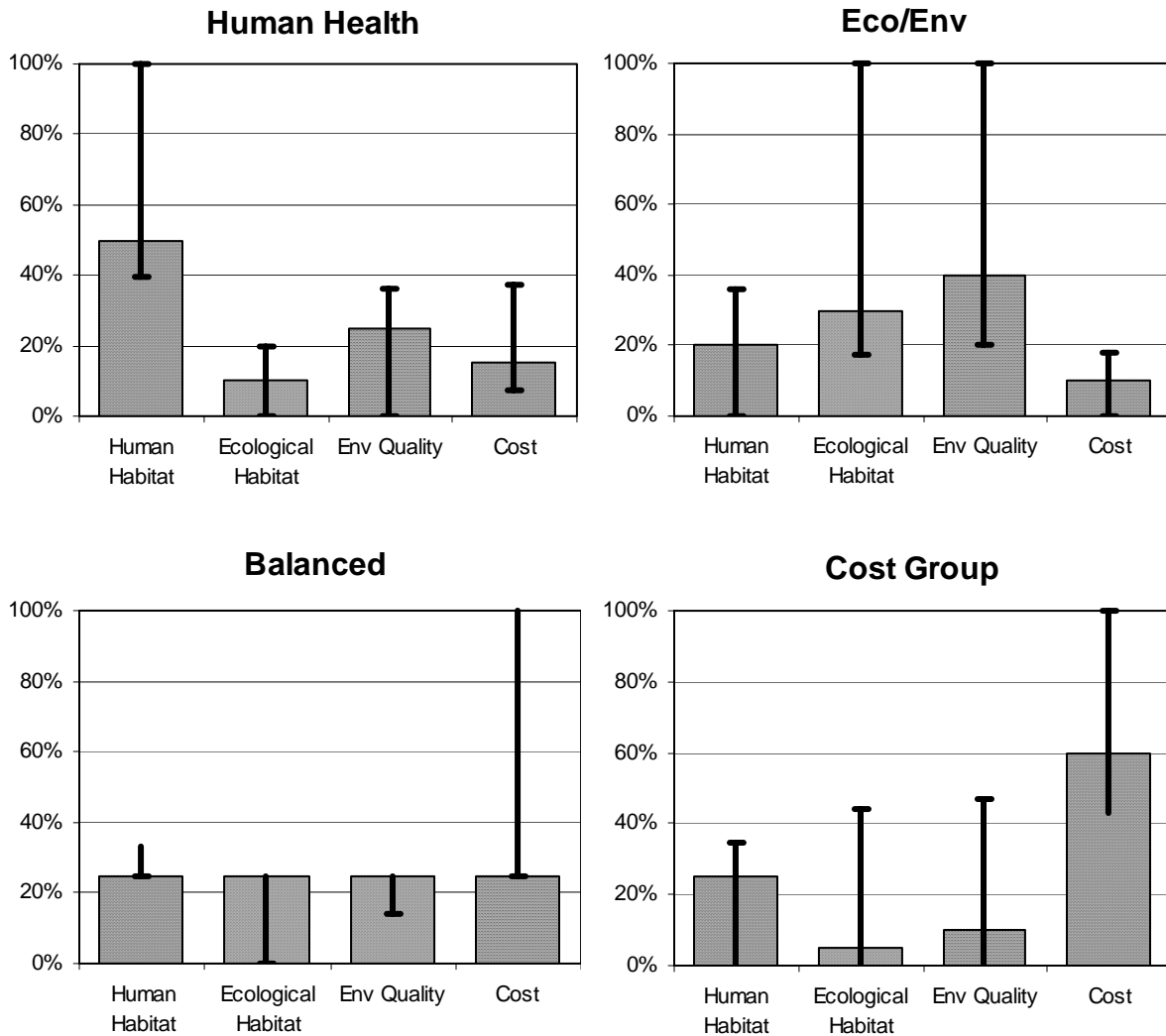


Figure 6: Stability intervals (represented as error bars) indicate the range of criteria weights over which the first two predicted preference orderings are unchanged. Upper bounds are indicative of the extent to which a criterion can be overweighted (at the equal expense of other criteria) without changing the top two predicted preferences. Lower bounds represent the potential extent of underweighting. Note that any change in the Balanced group would result in a reordering, due to the exact tie for second place.

The stability intervals show the strength of conviction in the Cost Group and the Eco/Env. Each may be considered highly unlikely to revise their views so drastically that their primary concern (cost or ecological habitat and environmental quality, respectively) actually becomes a secondary concern—although it may be possible. Similarly, the Human Health group seems fairly well placed within the middle range of the stability interval on each criterion. However, the preference ordering predicted for Human Health may be ambivalent about whether upland capped cell or cement manufacture is preferred. The latter is the first choice of the Cost Group, suggesting that Human Health may be persuaded to agree with Cost Group on the advantages of cement manufacture. In fact, cement manufacture is the only alternative that exists as first or second choice among all groups, perhaps suggesting a compromise that could be accepted by all groups. This is because, despite the drastically different priorities of the Cost Group and Eco/Environmental, according to the expert assessments, cement manufacture partially satisfies each.