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Analysis

Deliberative valuation without prices: A multiattribute prioritization for watershed ecosystem management

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ABSTRACT

Watershed ecosystems are characterized by multiple attributes which are difficult to collapse into single money-metric. Attribute ranking without prices and group deliberation can be used to process information about these complex systems. We develop this approach and use it with a stakeholder group to classify attributes in subwatersheds for restoration. We examine the relationship between individual valuation and valuation arrived from deliberation and information exchange by the group. While group consensus values tended toward an average of individual responses, significant differences existed between mean values and consensus values for some attributes, emphasizing the role of ecosystem attribute information and deliberation.

1. Introduction

Choices for natural resource and ecosystem protection often require information processing about multiple attributes of complex systems. We argue that attribute ranking without prices but including participatory deliberation can be used to process information about complex systems such as watershed ecosystems. Hypothetical valuation is often used to compress and commoditize this complexity into simple metrics of monetary values, resulting in the loss of information (Vatn and Bromley, 1994). In their seminal article, Vatn and Bromley (1994), challenge the presumption that environmental choices without prices are inferior to those using hypothetical valuation. In practice, a majority of decision making regarding natural resources and ecosystems has relied on attribute ranking without explicit use of money-metric prices. For example, decisions on land management have relied on zoning for land use without employing hypothetical values. Direct ranking, an approach often used in decision research, uses relative weights of attributes (Keeney and Raiffa, 1993) for the efficient allocation of resources. Such attribute-based methods are used in complex systems such as space exploration (Dole, et al., 1968), city planning (Schimpeler et al., 1969), watershed management (Shriver and Randhir, 2006), corporate policy (Keeney, 1975), nuclear power siting (Keeney and Nair, 1976), transport of hazardous material (Kalelkar et al., 1974), and water quality (O'Connor, 1973). While the valuation exercise in these cases is aimed at deriving relative values of attributes for decision making, monetary values were not emphasized in such complex decision problems. Ecosystems have complex, multiple attributes that are often difficult to express in single money metric. Freeman (1986) and Vatn and Bromley (1994) note that hypothetical valuation is of dubious merit for evaluating choices concerning entire habitats or ecosystems that cannot be easily commoditized. Martinez-Alier et al. (1998) observe that value incommensurability can be operationalized by means of multicriteria evaluation. We propose that attribute prioritization can be used to value ecosystems without pricing.

Participatory deliberation is another aspect of group decision making that is increasingly recognized as critical for ecosystem management. Stakeholder involvement is now an accepted part of environmental decision making (Carmin et al., 2003). While stakeholder involvement increases cost (Susskind, 1994) and time (Beierle and Cayford, 2002) of a project, it is better in reflecting wants and needs of diverse constituencies (Fiorino, 1990) and ensures greater trust in the decision making process and the outcomes (Beierle and Koninsky, 2000) related to resource management. Mandated by the U.S. National Environmental Policy Act (1969), and recognized as important to the planning process (Bishop, 1970), community values of ecosystem services are increasingly being incorporated into natural resource policy through stakeholder participation in decision making processes (Ross et al., 2002; Fagence, 1977). Society's acceptance of environmental decisions depends on methods that incorporate the views of stakeholders (Bishop, 1970). Thus, environmental decision making is moving away from an emphasis on the end result alone and toward an inclusive, deliberative process (O'Connor et al., 1996; Funtowicz and Ravetz, 1990). Deliberative methods are used to reach collective agreement about ecosystem values through a process of discussion and information sharing among stakeholders with varied

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views (Howarth and Wilson, 2006). Renn et al. (1995) observe that participatory and deliberative methods improve overall legitimacy of the decision making process. The value of stakeholder deliberations lies in social learning to arrive at a group consensus (Webler et al., 1995). The participation in deliberation improves fairness of the democratic process through legitimacy, social learning, and political equality (Messner et al., 2006). Hence, the process used to determine the preferences of stakeholders is an important part of a deliberative method. Key issues in these deliberative techniques are: the role of information exchange among participants in the deliberative process (Pestman, 1998), quantification of group preferences, and methods to aggregate and harmonize individual preferences in order to arrive at a group consensus. A deliberative method is needed that is relatively easy to use, aggregates stakeholder preferences, incorporates information exchange among stakeholders, and harmonizes[1] individual preferences to reach group consensus.

The objectives of this study are to: (i) Develop a deliberative framework for elucidating group preferences for multiple attributes in ecosystems; (ii) Study the relationship between harmonized and individual preferences; (iii) Assess the relationship between harmonized and aggregated preferences; and (iv) Identify specific attributes where harmonized preferences differ significantly from aggregated preferences. We hypothesize that: (i) A deliberative mechanism can be developed for deriving group preferences; (ii) Significant differences exist between individual preferences and deliberated group preferences; (iii) Deliberated group preferences tend towards aggregated preferences; that is, arithmetic or geometric means; (iv) Some ecosystem attributes have significant deviation between deliberated and aggregated values, emphasizing the role of information exchange and deliberation. We expect that a deliberative mechanism can be developed for assessing group preferences that are different from individual preferences. We expect that the deliberated preference tend toward aggregated preferences and are influenced by learning and information exchange.

In this study a deliberative technique, Deliberative Attribute Prioritization Procedure (DAPP), is developed and used with a panel of representative stakeholders to prioritize attributes of watershed impairment in order to classify subwatersheds for restoration need. The DAPP combines a multi-criteria analysis using pair-wise comparisons with a deliberative process to reach group consensus. "Consensus" in this context means reaching mutual agreement toward relative values of specific attributes that is acceptable to all parties (Raiffa, 2002) affected by the decision making process. The study examines the relationship between individual stakeholder priority weights compared to weights arrived at after a process of face-to-face discussion and information exchange by the same panel members.

2. Background

Preferences for ecosystem attributes can be prioritized without explicit imputation of monetary values. Non-monetary attribute prioritization reflects the human values placed on improving and protecting ecosystems and often incorporates group deliberations to aid management decisions.

Some researchers have used non-monetary attribute prioritization methods with stakeholder groups to prioritize management objectives. Clements et al. (1996) involved stakeholders in the process of prioritizing watershed management objectives by giving them environmental information about the watershed. Through a process of consensus building they prioritized and targeted issues of chief concern in order to develop watershed management strategies. Lamy et al. (2002) pursued a similar strategy whereby stakeholders prioritized watershed problems and identified areas for restoration within the context of a decision support system for decision makers. Renn (1999, 2006) proposes analytical-deliberation decision making process for risk management and environmental policies.

Non-monetary attribute prioritization in natural resource management has also been applied in situations where policy choices require a weighing of tradeoffs in pursuit of management objectives. For example, fisheries management studies in the United Kingdom (Mardle et al., 2004) and Trinidad and Tobago (Soma, 2003) used non-monetary attribute prioritization methods to rank stakeholder objectives in fisheries for economic, conservation, employment and governance purposes. Likewise, these methods have been used to weigh stakeholder views about forest management for timber production and biodiversity conservation (Kuusipalo and Kangas, 1994; Huang et al., 2002). Farmers, fishermen, sugar mill staff, local community members and environmentalists took part in a non-monetary attribute prioritization process to compare riparian revegetation options in a watershed in Australia (Qureshi and Harrison, 2001). Non-monetary prioritization methods have also been used to rank non-market, non-quantifiable attributes of conserved land in Delaware (Duke and Aull-Hyde, 2002) and to weigh the importance of environmental, agricultural, commercial and industrial issues affecting the National Park of Eastern Macedonia and Thrace in Greece (Pavlikakis and Tsihrintzis, 2003). Antunes et al. (2006) used mediated modeling (MM) approach which is a group model building exercise to protect coastal wetland in Portugal (2006).

Non-monetary attribute prioritization methods have been used as a tool to incorporate social and cultural values in wilderness assessment in Australia (Ananda and Herath, 2002) and to prioritize influential factors for determining the width of buffer zones around the Yancheng Biosphere Reserve in China (Li et al., 1999). Randhir et al. (2001) used a deliberative process to develop consensus in prioritizing land parcels to protect water quality at a watershed scale. The attributes included land characteristics and water travel time that contribute to changes in water quality.

Deliberative methods for environmental decision making can give stakeholders a wide range of information, provide a structure for evaluating and discussing complex information, incorporate a range of ethical, moral and monetary values and use methods for reaching consensus. These attributes can enhance the public participation process and confer greater legitimacy on the policy decisions (Howarth and Wilson, 2006). These methods to ascertain stakeholder preferences require two-way communication and information exchange among stakeholders and decision makers (Heathcote, 1998). Two-way communication in environmental decision making can allow participants to modify their positions on controversial matters and reach decisions that are more readily supported by the public (Stagl, 2004; Heathcote, 1998). Group processes for deliberation may include a variety of techniques for small groups such as brainstorming sessions to try to formulate new, creative solutions to environmental problems. Workshops with breakout groups allow members to discuss their preferences, report to the group at large and hear the results from other breakout groups. This process may reveal areas of strong disagreement or consensus among members. Working committees, public meetings, values clarification exercises and circle processes (Heathcote, 1998) also offer opportunities for stakeholders to exchange information, discuss their preferences and strive for consensus about environmental issues (Heathcote, 1998).

Deliberative methods may include discursive techniques such as the use of citizen juries in which small groups of community stakeholders deliberate environmental policies through a process of questioning experts, discussing the information presented and reaching common agreement (Perkins, 2004; Proctor and Drechsler, 2003; Sagoff, 1998). Each of these deliberative approaches has varying levels of information exchange and may or may not incorporate methods to quantify and harmonize group preferences.

Methods to incorporate stakeholder views have also been used in combination with multi-criteria analysis where stakeholders must

[1] Defined as movement of individual preferences toward group preference arrived through information exchange and consensus.

evaluate complex information and ascribe priority weights (Stagl, 2004; Proctor and Drechsler, 2003). A multi-criteria analysis (MCA) involves identification and evaluation of multiple alternatives and multiple criteria to arrive at a decision. Hajkowicz and Collins (2007) define MCA as a decision model which contains sets of decision options to be ranked, multiple criteria, and performance measures. Establishing criteria for ranking the options, assigning stakeholder weights or preferences and aggregation of preferences into a single rank order are a part of a multicriteria evaluation (Proctor and Drechsler, 2003). The Delphi Process (Linstone and Turoff, 1975) and Analytic Hierarchy Process (AHP) (Saaty, 1999) are procedures for multi-criteria analysis now being used in natural resource management as decision support systems (Ananda, 2007; Mardle et al., 2004; Pavlikakis and Tsihrintzis, 2003; Soma, 2003; Ananda and Herath, 2002; Duke and Aull-Hyde, 2002; Huang et al., 2002; Kang, 2002; Qureshi and Harrison, 2001; Marcot et al., 2001; Li et al., 1999; Kuusipalo and Kangas, 1994).

The Delphi Process uses an iterative procedure to reach group consensus in which participants receive questionnaires and record their preferences through a series of pair-wise comparisons to rank choices. Successive questionnaires incorporate the responses of group members to previous questionnaires, and participants are asked to again assign preferences based on the information they receive (Heathcote, 1998). Participants exchange information through this process which allows for harmonization of viewpoints, but they do not meet face-to-face.

The AHP is another tool to advice decision-makers through an iterative process (Saaty, 1999) and has broad application for decision-making in complex environments, particularly where disparate or conflicting elements must be compared and weighed. The AHP develops a hierarchy of goals, attributes or measures and rates the importance of each in relation to the others through pair-wise comparisons. The power of the AHP lies in its ability to quantify the degree of agreement among participants. When individuals have given their preferences and ascribed priority weights, the group preference may be established by finding the arithmetic mean of individual preferences (Mardle et al., 2004; Soma, 2003; Kang, 2002) or by calculating the geometric mean (Duke and Aull-Hyde, 2002; Saaty, 1989) to determine the group preference. However, these approaches may be inadequate to represent the group preference since they do not incorporate a deliberative process which allows for information exchange, learning and harmonization by participants. As a result subsequent conflicts could arise.

Attribute based methods are appropriate in decision making related to complex systems like watershed ecosystems. This method assumes that the values and preferences of the ecosystem are derived from individual attributes. This is similar to conjoint method in attributes of a commodity. The use of attribute based methods for participatory decision making is that the participants can deliberate attributes more easily than trying to evaluate the ecosystem as a whole. An attribute-based method also allows identification of dominant attributes, testing for consistency, and in use in multi-criteria analysis (MCA). The deliberated outcome can then be used decision making related to protecting and managing larger watershed systems.

This study aims to elucidate the value of information exchange in arriving at group preferences for attributes of a watershed ecosystem. Non-deliberative methods that derive group preferences from the arithmetic and geometric means of individual preferences are compared with a group decision based on a deliberative process of information exchange among stakeholders. Information exchange adds a learning process which harmonizes individual preferences to reach group consensus. Where harmonized preferences converge through stakeholder discussions, decision makers may find strong agreement about environmental decisions. Where preferences fail to converge, decision makers may receive information important for avoiding later conflicts.

The DAPP uses the methods of pair-wise comparisons and calculations of the AHP to assign priority weights to rank choices. To the AHP it adds a qualitative process of face-to-face information exchange by stakeholders and a reevaluation of preferences to reach a group consensus. The DAPP also incorporates procedures of the Delphi Process by allowing participants to reflect on group consensus values over time and suggest changes to those preferences. This study also includes a process to examine group preferences (pair-wise comparisons) for consistency (Soma, 2003; Kang, 2002; Kuusipalo and Kangas, 1994; Saaty, 1994) and check them for intransitivity.

2.1. Watershed ecosystems

Watershed systems are widely recognized as fundamental geographic units for managing natural systems in a landscape (USEPA, 2000; Williams et al., 1997) and are a reference for understanding interactions among the underlying geology, topography, soils, water, plants, animals and human beings. An important aspect of watershed management is the human dimension. The nature of watershed use depends on the values, norms and interactions of stakeholders.

Human impacts of urbanization, agriculture, industrialization and the laws, policies and cultural traditions that govern human activity can be observed in the quantity and quality of water and soils and the abundance and diversity of plants and animals in the watershed. Policies and strategies to restore and sustain watershed health require an assessment of the condition of the abiotic, biotic and human systems within the watershed and a process to gauge the relative importance of these watershed attributes.

An assessment of multiple attributes of impairment to the biophysical and human parts of the watershed system provides crucial information to guide stakeholders and decision makers in forming restoration choices. But restoration actions also depend on the prioritization of restoration needs. Prioritization ultimately reflects the human values placed on improving and protecting elements of the watershed system and is shaped by the group interaction of participants and the process of building consensus for watershed restoration actions. Here group interaction involves exchange of information to arrive at a group consensus on watershed restoration. Therefore restoration decisions depend on a weighing and balancing of interests. The prioritization process is shaped by the breadth of viewpoints represented and the methods used to assess people's views. A methodology to classify watersheds for restoration need should both quantify attributes of watershed impairment and incorporate a quantitative process for assessing human priorities. Prioritization allows indicators of impairment to be given relative weights based on stakeholder values so that a composite measure of impairment at the subwatershed scale can be developed and relative degradation compared.

Some researchers have analyzed watershed processes to prioritize areas for protection to maintain water quality (Randhir et al., 2001; Richardson and Gatti, 1999; Lent et al., 1998; Llewellyn et al., 1996; Frissell et al., 1993.) Still others have used stakeholder groups to prioritize management objectives (Clements et al., 1996; Lamy et al., 2002; Heathcote, 1998; Coplin et al., 1983).

The literature on prioritization models shows limited studies which combine information about a broad array of biophysical characteristics with assessment or ranking by stakeholders. The current research prioritizes restoration need based upon two processes — a quantification of watershed impairment and prioritization with weights determined by expert opinion through the Deliberative Attribute Prioritization Procedure. This approach can serve as a management tool and a decision support system to protect ecosystems.

The DAPP has been used with a panel of expert stakeholders to ascribe weights to fourteen abiotic (runoff, wetland density, sediment, nitrogen, phosphorus and dissolved oxygen), biotic (percent core/

priority habitat, potential numbers of species of herptiles, birds and mammals and forest fragmentation) and human attributes (effective impervious area, population density and density of toxic waste sites) of watershed impairment in order to derive a composite index of restoration need at the subwatershed scale. Individuals gave scaled values for paired comparisons of each attribute. A period of discussion and information exchange followed during which the panel reached agreement on scaled values for each of the paired comparisons (after Randhir et al., 2001). After the session concluded, panelists were given an opportunity during the following week to review and alter the group values subject to the approval of other group members, thereby incorporating a feature of the Delphi Process. Prioritized weights of impairment attributes were then calculated on the basis of the group consensus values and examined for consistency by analyzing weights for transitivity. Based on microeconomic theory, human preferences are asymmetric and negatively transitive. Therefore, if a person prefers x over y, he cannot say that y is a better choice than x or his judgment is not rational and is therefore intransitive (Kreps, 1990). Such inconsistencies were adjusted for consistency using ranking values expressed through other attributes.

3. Methods

We follow Howarth and Wilson (2006) in developing the conceptual model for this study. Let a small group of n individuals represent major stakeholders in the watershed. An individual i in the group has a preference for an attribute through a value function $v_i(x_a)$ that reflects individual i's value on the contribution of the attribute a (relative to another attribute a') to the performance of the watershed ecosystem. Here performance of an attribute can be defined as relative contribution of the attribute to the goal of restoring a watershed system. This value can be represented as the individual i's preference for an attribute to improve or restore the functioning of the watershed ecosystem compared to other attributes. The individual i, will, under rational conditions, strictly prefer an attribute a over a' if $v_i(x_a)>v_i(x_{a'})$. The value function thus reflects a person's preference, beliefs, and moral judgments toward the importance of that attribute to the watershed system.

The group preferences, $v^G(x_a)$ are defined as the agreed-upon (harmonized) values of attributes ($x_a \in X$) for a watershed that improve the performance of the watershed. These group values may be reached through a deliberation process of information exchange and mutual consent. The deliberation process undertakes an exhaustive discussion, information exchange, and comparison of each pair x_a, $x_{a'} \in X$ to evaluate the preference of one attribute (a) in relation to the other (a') as measured through the value functions $v^G(x_a)$. The group under rational conditions will strictly prefer an attribute a over a', if $v^G(x_a)>v^G(x_{a'})$. While $v^G(x_a)$ is an agreed upon value that is desirable to the group, there is no presumption that this is also the same as $v_i(x_a)$ for any individual i.

The deliberated group values $v^G(x_a)$ are often critical in decision making related to the management of watershed ecosystems and in the development of land use policies. A common approach in deriving group values is through the aggregation of individual values. This aggregation is often arithmetic averaging as in the survey means used in the valuation literature (mean WTP), or geometric averaging as the product of incremental values of individuals in the bargaining literature (e.g. Mariotti, 1999). While aggregation of individual preferences can result in estimates of group preferences, these estimates do not incorporate adjustments to reflect the deliberation among individuals.

We compare outcomes of the group preferences that are aggregated to those derived from a deliberation process.

3.1. Deliberative attribute prioritization procedure

In the DAPP, a hierarchy of homogeneous groups (Saaty, 1999) is created so that any element in one level can be related to some elements in the next higher level. Participants were asked to complete pair-wise comparisons and fill in a matrix in which each element of the hierarchy was compared and ranked for its importance against every other member of the hierarchy and rated on a scale of 1 (equal importance) to 9 (extreme importance). The intermediate values 2 through 8 are assigned gradual increase in the level of importance (Saaty, 1999). If the element is less important than the one with which it is compared, a reciprocal value is entered in the matrix. In this method, the judgements are thus based on the fundamental scale {1/9,1/8,..,1,..,8,9} (Terán and Moreno-Jiménez, 2008). Consider elements of attribute set, $x_a \in X$, $a=1,\ldots,n$ and relative weight of x_i with respect to x_j be w_{ij}, then a square reciprocal matrix $W= w_{ij}$, represents weights derived from all pairs. For example, the element in first row, second column (1,2) in Table 1 is 4, indicating that Runoff moderately important than Wetland density in a watershed system. Similarly, element (2,3) in Table 1 is ½ indicating weak importance of sediment yield over wetland density in a watershed. The use of this numbered scale is recommended for group decision making (Saaty, 1999; Randhir et al., 2001) to enable clarity in communication, consistency in relative importance, and guided facilitation of deliberation between any two pairs. Such relative and standardized scale will enable use of same baseline in judgments by all participants.

The eigen value method (Saaty, 1999) that results in a priority vector and inconsistency number (λ_{max}) uses the following steps: 1.) The values in each column are summed and each entry is divided by the column total to obtain a normalized matrix of values thereby allowing a meaningful comparison of the elements. 2.) Each row is then summed and divided by the number of entries in the row to get relative weights. 3.) A test for consistency is applied by calculating

Table 1
Group consensus values (adjusted for consistency).

	RO	Wetl dens	Sed yld	Eutro nutrs N, P	DO	% core/prior habitat	Pot. no. spec herps	Pot. no. spec birds and mamms	For frag	EIA	Pop density	No toxic waste sites
RO	1	4	3	3	2	2	3	2	5	2	2	1/4
Wetl dens	1/4	1	1/2	1/3	3	1/2	2	1	1/2	1/3	1/2	1/3
Sed yld	1/3	2	1	1	2	3	2	2	2	1/2	2	1/3
Eutro nutrs N,P	1/3	3	1	1	1	3	3	3	1/2	1	1	1/2
DO	1/2	1/3	1/2	1	1	1/3	3	1	1	1/2	1/2	1/3
% core/prior habitat	1/2	2	1/3	1/3	3	1	2	1	1	1	1/3	1/3
Pot. no. spec. herps	1/3	1/2	1/2	1/3	1/3	1/2	1	2	1/2	1/2	1/4	1/3
Pot. no. spec. birds and mamms	1/2	1	1/2	1/3	1	1	1/2	1	1/2	1	1/2	1/3
For frag	1/5	2	1/2	2	1	1	2	2	1	1/3	1/2	1/3
EIA	1/2	3	2	1	2	1	2	1	3	1	2	1/3
Pop density	1/2	2	1/2	1	2	3	4	2	2	1/2	1	1/3
No. toxic waste sites	4	3	3	2	3	3	3	3	3	3	3	1

λ_{max} by multiplying each paired comparison value by its respective weight derived in step 2. The new row total is divided by the relative weights from step 2. 4.) These quotients are averaged to produce λ_{max}. 5.) A Consistency Index (CI) is calculated as follows:

$$CI = (\lambda_{max} - n) / (n - 1) \quad (1)$$

Where, n is the number of elements which form the matrix. 6.) The computed CI is divided by the random value of CI for a matrix of n elements (random value for matrix of 12 elements = 1.35) to determine the Consistency Ratio. In matrices of more than 4 elements, this value should be less than or equal to 10%, a confidence level suggested by Saaty (1999).

The DAPP was conducted with a panel of 10 representative stakeholders in a face-to-face session. The stakeholders are selected to represent major interest groups in the watershed with ecosystem components as a basis — biotic, abiotic, and socioeconomic interests. The selection is done by the authors with consideration toward a balance in representation. In advance of the meeting they were given information about the study, its methods and the DAPP. Representatives attended from the University of Massachusetts (UMass) Amherst Department of Plant and Soil Sciences, Department of Natural Resources Conservation, The Environmental Institute, Massachusetts Cooperative Fish and Wildlife Research Unit, the USDA Natural Resources Conservation Service, MA Department of Conservation and Recreation, Division of Water Supply Protection, the Pioneer Valley Regional Planning Commission and the MA Watershed Coalition, a nonprofit organization. Panelists contributed expertise in agriculture, citizen outreach, wildlife conservation, forestry, water quality, regional development and watershed science. The panelist represented major stakeholders in the watershed.

After a brief review of the aims and methods of the research and an explanation of the study's conceptual model, panelists were given a 12 × 12 matrix. (To simplify the pair-wise comparisons two attributes were combined with similar ones. The eutrophying nutrients, nitrogen and phosphorus were combined as were potential numbers of species of birds and mammals.) Panelists were asked to compare the impairment attributes in the left-hand column with all other attributes in the row across the top of the page for their relative importance in restoring the watershed as whole and give a value between 1 and 9. They were asked a set of questions about each indicator of impairment to frame the paired comparisons and provide consistent objectives for applying a numerical rank. In evaluating the relative importance of runoff, participants were asked:

Is reducing runoff more important than
Increasing wetland area,
Reducing sediment yield,
Reducing the eutrophying nutrients, nitrogen and phosphorus,
Increasing dissolved oxygen,
Protecting critical habitat for rare and endangered species,
Protecting habitat for herptiles,
Protecting habitat for birds and mammals,
Reducing forest fragmentation,
Reducing effective impervious area,
Reducing impacts of the urban core associated with population density and cleaning up toxic waste sites?

Each question was repeated in relation to all the other attribute questions. Panelists were told not to consider cost in making attribute comparisons, only the relative importance of attributes in relation to the health of the watershed as a whole. The participants then completed individual matrices. These were collected and photocopied for later reference. Panelists then discussed their individual rankings in order to reach agreement on a single, consensus value for each of 66 paired comparisons. The use of numbered scale of Saaty (1999) allows systematic processing of each pair with a standardized scale that can be used in decision making. The pairwise comparison using this 9-point preference elicitation scale forces the decision maker to explicitly consider the tradeoffs among attributes (Ananda, 2007). Saaty (2001) demonstrated that the integers used in 1–9 scale are consistent with Weber–Fechner law of response to stimuli (Dehaene, 2003).

Development of group consensus on all 66 pairs can be time consuming. To maximize use of meeting time, information on each attribute and general background of the watershed ecosystem is provided several days in advance to all participants. In addition each attribute is clearly outlined to all participants with respect to the overall watershed ecosystem. This allowed participants to be better prepared for deliberation process. Deliberation on each pair of attributes is facilitated and discussion is continued until a consensus is reached. Some pairs of attributes involved longer deliberation time, indicating more information exchange for those pairs. The 1–9 scale is useful in understanding the extent of dispersal in individual ranks and potential for group consensus. The final group consensus score is agreed by all participants.

In the group meeting panelists filled out their individual matrices to rank the relative importance of pairs of impairment attributes. Subsequently, the group worked to reach agreement on values for 66 paired comparisons. The facilitator picked paired attributes for discussion in a randomized fashion. This differed from the method employed by others (Randhir et al., 2001) in conducting an AHP whereby the facilitator began in the upper left-hand corner of the matrix and proceeded sequentially along the rows and columns. The randomized method of choosing pairs allowed for more debate about paired attributes from disparate portions of the matrix. Since lengthier discussion tends to take place among the first paired attributes and, due to time constraints, less debate takes place among pairs discussed later in the DAPP session; a randomized method of selecting pairs allows better discussion about all parts of the matrix.

The individual values of the expert panel often varied considerably, and ranged from 1/7 to 7 for certain pairs. Panelists debated the justification for their rankings and some panelists were reluctant to compromise. Lengthy discussion of the first paired comparisons allowed the group to represent their views and offer substantial justifications for their rankings. Within the first hour panelists exchanged much information and found, as the process continued, that little new information was added by prolonged debate. Thus, rankings for the remaining pairs moved more swiftly. The discussion mirrored the diversity of viewpoints, disinclination to compromise paired attribute values and the necessity, ultimately, to make choices that characterize restoration decision making. The DAPP provided the added benefit of quantifying the prioritization, ordering the process, assuring a face-to-face information exchange and prompting the group to reach agreement on paired attribute values.

At the end of the allotted time the group had reached agreement on all of the pairs. Panelists were given an additional 6 days to consider changes to the group consensus values, thus incorporating elements of the Delphi Process. One panelist suggested changes to two values to which the other panelists agreed. These group consensus values became the basis for the analysis and calculation of weights or priorities. While the face-to-face discussion of DAPP was focused in a single afternoon session, its preparation and completion with panelists spanned a period of approximately seven weeks. While some pairs of attributes took a longer time to deliberate, other pairs which most agree were harmonized quickly. Pairs that had a wider dispersion between individual weights had longer discussion, and deliberation for reaching a consensus.

Group consensus values were analyzed according to the process described above to determine priority weights for the indicators of impairment. The initial consistency ratio was 11.5%, greater than the maximum suggested by Saaty (1999). Inconsistency arises because individuals are making decisions considering complex information on tradeoffs and cannot make perfectly rational judgments, particularly when weighing the relative importance of dozens of paired attributes. This tendency mirrors the intricacy of environmental decision-making, and the DAPP method allows for the remediation of such inconsistencies.

In spite of providing detailed information about each attribute and acceptance of weights by all participants, there is a likelihood of inconsistency in group values. Group consensus values were therefore examined for consistency in transitivity property. If impairment attribute A>B and B>C, then A must also be >C. Where this is not true, the consensus value is inconsistent. Group consensus values for each attribute of impairment were compared with the other values and examined for intransitivity. Three types of inconsistencies were examined. 1.) In evaluating the importance of runoff, the panel agreed that reducing runoff was 3 times more important than reducing sediment yield, and that reducing sediment yield was 2 times as important as reducing forest fragmentation, but that reducing runoff was only ½ as important as reducing forest fragmentation. The latter value is inconsistent and was changed from ½ to 5 to better accord with the other panel judgments. 2.) Protecting critical habitat was deemed ½ as important as increasing dissolved oxygen. This score was inconsistent with the importance of protecting critical habitat in relation to values for increasing wetland area and reducing EIA and was therefore changed to 3 to improve consistency. 3.) Protecting critical habitat was rated as being of equal importance (score of 1) with reducing runoff. This judgment led to inconsistencies of the relationship of habitat protection with increasing wetland area, reducing sediment yield, reducing eutrophying nutrients, increasing dissolved oxygen and reducing impacts of the urban core associated with population density. The value was revised to ½, indicating that protecting critical habitat is less important than reducing runoff. The latter two changes eliminated the major sources of inconsistency in the group consensus values. The revisions for consistency were agreed by the panel in a follow-up review.

3.2. Study area

The DAPP process was applied in a study of the Chicopee River Watershed of western Massachusetts and its 209 subbasins. The watershed covers 187,066 ha (1871 km^2) and is comprised of a mixture of rural, heavily forested lands, agricultural, suburban and urbanized areas. The watershed is drained by four major rivers, the Swift, Ware, Quaboag and Chicopee (main stem). The Quabbin Reservoir covers roughly 10,300 ha of the northwest portion of the watershed. Approximately 155 MGD of water from the Quabbin are transferred out of the Chicopee watershed to supply drinking water to the Boston area (MWRA, 2003). The watershed is comprised of all or part of 39 towns with a population of approximately 190,600 (2000 Census). The topography consists of rolling hills, alluvial plains and is dotted with numerous lakes and ponds. The land rises to a height of 457 m above sea level in the northeastern part of the watershed and drops to 12 m in the southwest corner of the watershed on the Connecticut River floodplain (MA DEP, 2001). The most heavily urbanized regions are in the south and southwest portions of the watershed in the towns of Chicopee, Springfield, Ludlow and Palmer. Nonpoint source pollution associated with storm runoff, septic systems, dumps and agriculture contributes to water quality problems (MA DEP, 2001).

4. Results

The group consensus matrix adjusted for consistency is presented below (Table 1). The consistency ratio is 5.4%, well below the value of 10% recommended by Saaty (1999).

Table 2 shows that the density of toxic waste sites has the highest priority weight with a value of 0.19. Runoff has the next highest ranking with a priority weight of 0.15. Weights for potential numbers of species of birds and mammals are given the lowest values at 0.025 for each. The weights of the remaining attributes range between 0.04 and 0.09. These weights were used in computing the composite index of impairment for 12 attributes to determine relative impairment of the subbasins.

The priority weights and their variance from group consensus weights for the individual panelists were calculated to analyze the relationship of individual weights to those of the group (Table 2). (Three panelists did not complete all paired comparisons in the matrix; therefore, those results were eliminated from the above analysis of panelist weights. Eight panelists deliberated to reach group consensus values.) Shaded rectangles in Table 2 indicate panelist weights that are within 1% of the group consensus weights. These values also have the smallest variances from the group consensus values. The watershed science representative had five weights within 1% of the group consensus weights; the citizen outreach representative had four weights within 1% of the group weights. The wildlife and water quality representatives each had one weight within 1% of the group weights. The latter results might suggest that the wildlife and water quality representatives had little influence on the group. Indeed their paired attribute rankings were often at opposite ends of the scale. However, their contributions during the discussion had important impacts on the group consensus values.

The graph in Fig. 1 shows the relationship of individual panelist weights to the group consensus values for each of the major attribute components, abiotic, biotic and human. With respect to the abiotic component most panelist weights cluster near the group consensus values. The water quality representative tended to place high priority on the indicators of runoff, wetland density, sediment yield, eutrophying nutrients and dissolved oxygen. The wildlife representative gave correspondingly low values to these indicators, except in the case of wetland density, where the two representatives were in close agreement.

With respect to the biotic component the roles of the water quality and wildlife representatives are reversed, with the water quality representative giving relatively lower priority to the biotic indicators, whereas the wildlife representative supported higher weights than the group consensus values. The watershed science representative gave uniquely high weights for core/priority habitat and forest fragmentation, values that did not appear to strongly influence the group weights.

Priority weights for attributes of the human component cluster closely to the group value and show relative agreement among panelists, except in the weighing of the importance of the number of toxic waste sites. For that indicator individual weights are widely dispersed with the forestry representative giving that attribute a very high relative value and the watershed science representative and citizen outreach representatives giving relatively low weights.

The relationship of the group consensus weights to the arithmetic and geometric means of panelist weights was analyzed to determine if there were significant differences. Group consensus weights and the arithmetic and geometric mean panelist weights correspond closely for majority of the attributes (Fig. 2).

A student's t-test for the significance of difference between two means was used to compare the difference between average panelist weights and group consensus weights for each of the 12 attributes used in the paired comparison matrix using the formula:

$$t = \bar{x}_1 - \bar{x}_2 / \sqrt{s^2(1/n_1 + 1/n_2)} \quad (2)$$

where, $\bar{x}_1$ is the average panelist weight; $\bar{x}_2$ is the group consensus weight; $n_1 = 7$; i.e., number of panelists contributing to the average; $n_2 = 8$; i.e., number of panelists contributing the group consensus values. The formula for s^2 in Eq. (2) is as follows:

$$s^2 = (n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 / n_1 + n_2 - 2 \ \text{ where} \quad (3)$$

s_1^2 is the variance for average panelist weights and s_2^2 is the variance for group consensus weights. However, in the above formula the value

Table 2
DAPP individual panelist weights and group consensus weights.

Attribute	Group	Wildlife	Watershed	Regional development	Agriculture	Citizen outreach	Forestry	Water quality
Runoff	0.15	0.03 (0.01435)	0.08 (0.00429)	0.10 (0.00211)	0.08 (0.00379)	0.04 (0.01120)	0.11 (0.00129)	0.22 (0.00492)
Wetland Density	0.05	0.08 (0.00075)	0.04 (0.00001)	0.02 (0.00073)	0.04 (0.00002)	0.04 (0.00013)	0.02 (0.00098)	0.08 (0.00122)
Sediment	0.09	0.03 (0.00291)	0.06 (0.00054)	0.06 (0.00085)	0.04 (0.00188)	0.08 (0.00007)	0.06 (0.00099)	0.11 (0.00047)
Eutroph Nutrs N,P	0.09	0.03 (0.00353)	0.06 (0.00088)	0.05 (0.00128)	0.16 (0.00517)	0.05 (0.00122)	0.09 (0.00001)	0.13 (0.00154)
Dissolved Oxygen	0.05	0.03 (0.00038)	0.06 (0.00003)	0.16 (0.01230)	0.14 (0.00807)	0.10 (0.00217)	0.09 (0.00164)	0.05 (0.00001)
Core/ Prior Habitat (%)	0.06	0.09 (0.00109)	0.15 (0.00735)	0.04 (0.00066)	0.08 (0.00052)	0.13 (0.00441)	0.02 (0.00203)	0.02 (0.00166)
Herptiles	0.04	0.09 (0.00298)	0.05 (0.00024)	0.05 (0.00015)	0.07 (0.00080)	0.04 (0.00001)	0.02 (0.00046)	0.02 (0.00029)
Birds & Mamms	0.05	0.10 (0.00326)	0.05 (0.00000)	0.03 (0.00036)	0.05 (0.00000)	0.12 (0.00576)	0.02 (0.00085)	0.02 (0.00062)
Forest Frag	0.06	0.07 (0.00004)	0.27 (0.04254)	0.06 (0.00001)	0.10 (0.00168)	0.10 (0.00176)	0.05 (0.00022)	0.04 (0.00048)
EIA (%)	0.09	0.02 (0.00527)	0.06 (0.00094)	0.12 (0.00075)	0.03 (0.00422)	0.20 (0.01060)	0.10 (0.00005)	0.14 (0.00253)
Pop Dens	0.09	0.17 (0.00672)	0.09 (0.00002)	0.10 (0.00022)	0.02 (0.00427)	0.08 (0.00001)	0.05 (0.00001)	0.06 (0.00079)
Toxic Waste Sites (#)	0.19	0.26 (0.00416)	0.03 (0.02729)	0.21 (0.00041)	0.18 (0.00023)	0.02 (0.02986)	0.39 (0.03809)	0.11 (0.00762)

(Values in parentheses are the variances from the Group value. Shaded areas indicate panelist weights within 1% of group consensus weights.).

of $(n_2-1)\ s_2^2=0$ because by definition there is no variance among group consensus values. Thus the actual formula for s^2 was:

$$s^2 = (n_1-1)s_1^2 / n_1 + n_2 - 2 \quad (4)$$

Application of the formula led to the following results (Tables 3 and 4). Table 3 indicates that the arithmetic mean of panelist weights were significantly different from group consensus values for 4 of the 12 attributes, runoff, sediment yield, dissolved oxygen and forest fragmentation at $p<0.10$. The differences were highly significant for runoff and sediment yield ($p<0.01$). In the case of wetland density and potential numbers of species of birds and mammals average panelist weights were equal to group consensus values, and for all other attributes the differences between arithmetic mean panelist weights and group values were not significant at $p<0.10$.

Table 4 shows that the geometric means of panelist weights were also significantly different from group consensus values for 4 of the 12 attributes, runoff, sediment yield, dissolved oxygen and number of toxic waste sites. As was the case with the arithmetic mean, geometric means for runoff and sediment yield were highly significant ($p<0.01$).

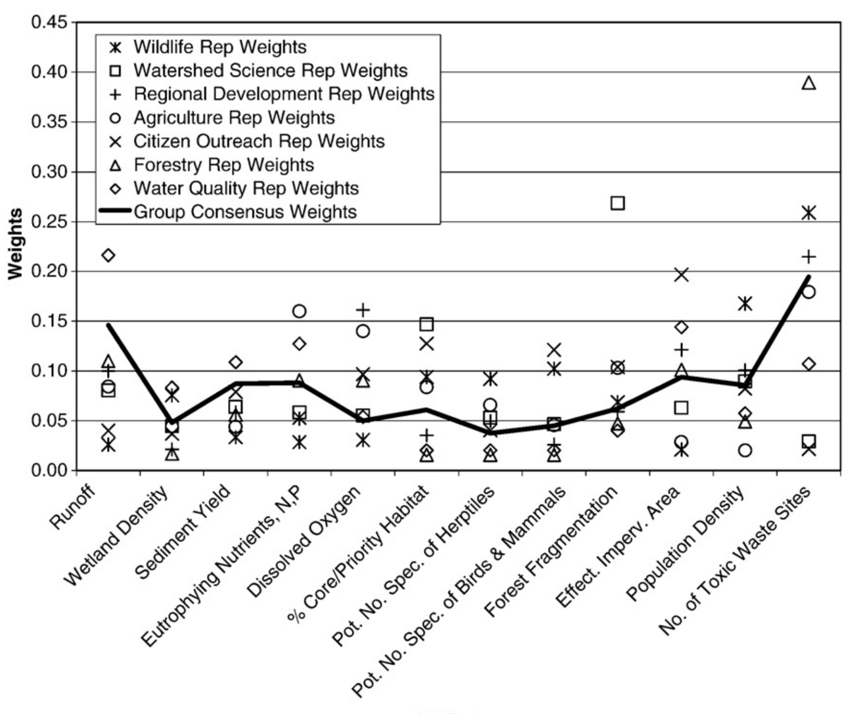

Fig. 1. Relationship of panelist weights to group consensus weights for attributes of impairment.

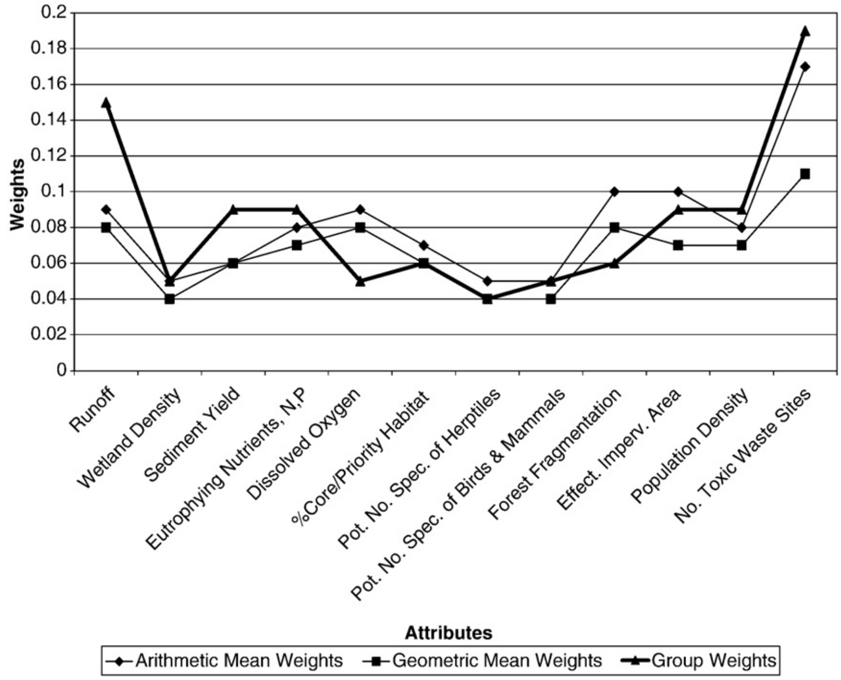

Fig. 2. Correspondence of average priority weights of panelists with group consensus weights.

Geometric mean panelist weights for percent of core and priority habitat and potential numbers of species of herptiles were equal to group consensus values and for all other attributes the differences between average panelist weights and group values were not significant at $p<0.10$.

Thus, while panelists showed a tendency to average responses in reaching group consensus values, significant differences between mean values and the harmonized values exist for 5 of the 12 attributes. Such differences may often exist in group decision making (Coplin et al., 1983). Study results suggest that exchange of information among panelists through a deliberative process such as the DAPP brings qualitative benefits to a group process for increasing understanding among a group whose members have disparate views. A process which harmonizes group values may therefore provide more reliable information for decision makers and reduce the potential for later conflicts among stakeholders.

5. Conclusions

This study develops a non-monetary, deliberative method (Deliberative Attribute Prioritization Procedure — DAPP) to assess group preferences for multiple attributes of watershed impairment. The method is relatively easy to use, aggregates stakeholder preferences, incorporates information exchange among stakeholders, and harmonizes individual preferences to reach group consensus. It may be used as a decision support tool for natural resource management.

The method was applied in a study of the Chicopee Watershed of western Massachusetts, USA. Representative stakeholders prioritized attributes of watershed impairment in order to classify subwatersheds for restoration need. The DAPP combines a multi-criteria analysis using pair-wise comparisons with a process to reach group consensus. The study examines the relationship between individual priority weights compared to weights arrived at after a process of face-to-face discussion and information exchange by the same panel members.

A general observation is that deliberative method is useful in watershed management that involves stakeholder values and multiple attributes. The DAPP procedure was well received by the participants for systematically evaluating each pair of attribute, inclusion of stakeholder values, and the potential for cooperative efforts. Information exchange increased potential for consensus among the participants. The deliberative mechanism can be applied to other issues for assessing group preferences and assessment of the extent of variation in individual preferences. A main conclusion is that mutual learning and information exchange by the group through deliberative methods is critical to develop group consensus for watershed management. Potential pitfalls that need to be considered

Table 3
Significance of difference between arithmetic mean of panelist weights and group consensus weights (critical values of *t* from McClave and Benson 1988; *t*-value calculated with 13 *df.*).

Attributes	(1) Average panelist weights	(2) Group weights	Difference (1)–(2)	Standard deviation	Significance of difference?
Runoff	0.09	0.15	−0.06	0.06	*Yes* Signif @ $\alpha=0.01$; $t=2.817$
Wetland density	0.05	0.05	0.00	0.03	*No* Wts. equal; thus no signif. diff.
Sediment yield	0.06	0.09	−0.03	0.02	*Yes* Signif @ $\alpha=0.0005$; $t=5.792$
Eutrophying nutrients, N,P	0.08	0.09	−0.01	0.05	*No* $p>0.10$; $t=0.568$
Dissolved oxygen	0.09	0.05	0.04	0.05	*Yes* Signif @ $\alpha=0.025$; $t=2.273$
% core/priority habitat	0.07	0.06	0.01	0.05	*No* $p>0.10$; $t=0.568$
Pot. no. spec. of herptiles	0.05	0.04	0.01	0.03	*No* $p>0.10$; $t=0.943$
Pot. no. spec. of birds and mammals	0.05	0.05	0.00	0.04	*No* Wts. equal; thus no signif. diff.
Forest fragmentation	0.10	0.06	0.04	0.08	*Yes* Signif @ $\alpha=0.10$; $t=1.413$
Effect. imperv. area	0.10	0.09	0.01	0.06	*No* $p>0.10$; $t=0.469$
Population density	0.08	0.09	−0.01	0.05	*No* $p>0.10$; $t=0.559$
No. of toxic waste sites	0.17	0.19	−0.02	0.13	*No* $p>0.10$; $t=0.407$

Table 4
Significance of difference between geometric mean of panelist weights and group consensus weights (critical values of *t* from McClave and Benson 1988; *t*-value calculated with 13 *df.*).

Attributes	(1) Average panelist weights	(2) Group weights	Difference (1)–(2)	Standard deviation	Signif of difference?
Runoff	0.08	0.15	−0.07	0.06	*Yes* Signif @ $\alpha=0.01$; $t=3.084$
Wetland density	0.04	0.05	0.01	0.03	*No* $p>0.10$; $t=1.102$
Sediment yield	0.06	0.09	−0.03	0.02	*Yes* Signif @ $\alpha=0.0005$; $t=5.071$
Eutrophying nutrients, N,P	0.07	0.09	−0.02	0.05	*No* $p>0.10$; $t=1.153$
Dissolved oxygen	0.08	0.05	0.03	0.05	*Yes* Signif @ $\alpha=0.10$; $t=1.748$
% core/priority habitat	0.06	0.06	0.00	0.05	*No* Wts. equal; thus no signif. diff.
Pot. no. spec. of herptiles	0.04	0.04	0.00	0.03	*No* Wts. equal; thus no signif. diff.
Pot. no. spec. of birds and mammals	0.04	0.05	−0.01	0.04	*No* $p>0.10$; $t=0.661$
Forest fragmentation	0.08	0.06	0.02	0.08	*No* $p>0.10$; $t=0.698$
Effect. imperv. area	0.07	0.09	−0.02	0.07	*No* $p>0.10$; $t=0.813$
Population density	0.07	0.09	−0.02	0.05	*No* $p>0.10$; $t=1.177$
No. of toxic waste sites	0.11	0.19	−0.08	0.15	*Yes* Signif @ $\alpha=0.10$; $t=1.544$

in designing and applying the procedure include: no consensus in group weights (Cookson, 2000); missed or deleted attributes (Weiss and Rao, 2007); and rank reversal when new attributes are introduced (Schoner and Wedley, 2007). These issues can be minimized through careful design of the deliberation process.

While group consensus values tended toward the arithmetic and/or geometric means of individual responses, significant differences existed between mean values and group consensus values for some attributes of impairment. These deviations emphasize the value of information exchange and deliberation in order to ascertain group preferences and may help avoid future conflicts. Similar results were obtained by Randhir et al. (2001) Study results also support the use of non-monetary, deliberative methods based on multiple attributes in decisions related to complex ecosystems.

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References

Ananda, J., 2007. Implementing participatory decision making in forest planning. Environmental Management 39, 534–544.
Ananda, J., Herath, G., 2002. Assessment of wilderness quality using the Analytic Hierarchy Process. Tourism Economics 8 (2), 189–206.
Antunes, P., Santos, R., Videira, N., 2006. Participatory decision making for sustainable development—the use of mediated modelling techniques. Land Use Policy 23, 44–52.
Beierle, T., Cayford, J., 2002. Democracy in practice: public participation in environmental decisions. Resources for the Future, Washington, DC.
Beierle, T.C., Koninsky, D.M., 2000. Values, conflict, and trust in participatory environmental planning. Journal of Policy Analysis and Management 19 (4), 587–602.
Bishop, B., 1970. Public participation in planning: a multi-media course. IWR Report 70–7. U.S. Army Corps of Engineers Institute for Water Resources, Fort Belvoir, VA.
Carmin, J., Darnall, N., Mil-Homens, J., 2003. Stakeholder involvement in the design of U.S. voluntary environmental programs: does sponsorship matter? Policy Studies Journal 31 (4), 527–543.
Clements, T., Creager, C., Butcher, J., 1996. Framework for Watershed Management. Watershed 96 Proceedings, Moving Ahead Together Technical Conference, June 8–12, 1996, p. 852. Baltimore, Maryland.
Cookson, R., 2000. Incorporating psycho-social considerations into health valuation: an experimental study. Journal of Health Economics 19, 369–401.
Coplin, W.D., McMaster, D.J., O'Leary, M.K., 1983. Creating a policy profile. In: public involvement techniques: a reader of ten years experience at the institute for water resources. In: Creighton, J.L., Delli Priscoli, J., Dunning, C.M. (Eds.), IWR Research Report 82-R1. InInstitute for Water Resources, US Army Corps of Engineers, Fort Belvoir, Virginia.
Dehaene, S., 2003. The neural basis of the Weber–Fechner law: a logarithmic mental number line. Trends in Cognitive Sciences 7 (4), 145–147.
Dole, S.H., Campbell, H.G., Dreyfuss, D., Gosch, W.D., Harris, E.D., Lewis, D.E., Parker, T.M., Ranftl, J.W., String Jr., J., 1968. Methodologies for analyzing the comparative effectiveness and costs of alternate space plans. RM-5656-NASA, Vol. 2. The Rand Corporation, Santa Monica, CA.
Duke, J.M., Aull-Hyde, R., 2002. Identifying public preferences for land preservation using the analytic hierarchy process. Ecological Economics 42, 131–145.
Fagence, M., 1977. Citizen participation in planning. Pergamon Press, Oxford, U.K.
Fiorino, D.J., 1990. Citizen participation and environmental risk: a survey of institutional mechanisms. Science, Technology, and Human Values 15 (2), 226–243.
Freeman, A.M., 1986. On assessing the state of the arts of the contingent valuation methods of valuing environmental changesIn: Cummings, R.G., Brookshire, D.S., Schulze, W.D. (Eds.), Valuing environmental goods. Rowan Allenheld, Totowa, N.Y.
Frissell, C.A., Liss, W.J., Bayles, D., 1993. An integrated biophysical strategy for ecological restoration of large watersheds. In: Potts, D.F. (Ed.), Changing Roles in Water Resources Management and Policy. American Water Resources Association, Bethesda, Maryland, pp. 449–456.
Funtowicz, S.O., Ravetz, J., 1990. Uncertainty and quality in science for policy. Kluwer, Dordrecht.
Hajkowicz, S., Collins, K., 2007. A review of multiple criteria analysis for water resource planning and management. Water Resources Management 21 (9), 1573–1650.
Heathcote, I.W., 1998. Integrated watershed management principles and practices. John Wiley and Sons, New York, pp. 112–125.
Howarth, R.B., Wilson, M.A., 2006. A theoretical approach to deliberative valuation: aggregation by mutual consent. Land Economics 82 (1), 1–16.
Huang, W., Luukkanen, O., Johanson, S., Kaarakka, V., Raisanen, S., Vihemaki, H., 2002. Agroforestry for biodiversity conservation of nature reserves: functional group identification and analysis. Agroforestry Systems 55 (1), 65–72.
Kang, 2002. A sensitivity analysis of the Korean composite environmental index. Ecological Economics 43 (2–3), 159–174.
Kalelkar, A.S., Partridge, L.J., Brooks, R.E., 1974. Decision analysis in hazardous material transportation. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. American Institute of Chemical Engineers, San Francisco, CA, USA.
Keeney, R.L., 1975. Examining corporate policy using multiattribute utility analysis. Sloan Management Review 17, 63–76.
Keeney, R.L., Raiffa, H., 1993. Decisions with multiple objectives: preference and value tradeoffs. Cambridge University Press.
Keeney, R.L., Nair, K., 1976. Evaluating potential nuclear power plant sites in the Pacific Northwest using decision analysis. PP-76-1. International Institute for Applied Systems Analysis, Laxenburg, Austria.
Kreps, D.M., 1990. A course in microeconomic theory. Princeton University Press, Princeton, New Jersey, pp. 19–21.
Kuusipalo, J., Kangas, J., 1994. Managing biodiversity in a forestry environment. Conservation Biology 8 (2), 450–460.
Lamy, F., Bolte, J., Santlemann, M., Smith, C., 2002. Development and evaluation of multiple-objective decision-making methods for watershed management planning. Journal of the American Water Resources Association 38 (2), 517–529.
Lent, R.M., Waldron, M.C., Rader, J.C., 1998. Multivariate classification of small order watersheds in the Quabbin Reservoir Basin, Massachusetts. Journal of the American Water Resources Association 34 (2), 439–450.
Li, W., Wang, Z., Tang, H., 1999. Designing the buffer zone of a nature reserve: a case study in Yancheng Biosphere Reserve, China. Biological Conservation 90, 159–165.
Linstone, H.A., Turoff, M. (Eds.), 1975. The Delphi method: techniques and applications. Addison–Wesley Publishing, Boston, MA. 620 pp.
Llewellyn, D.W., Shaffer, G.P., Jo Craig, N., Creasman, L., Pashley, D., Swan, M., Brown, C., 1996. A decision-support system for prioritizing restoration sites on the Mississippi River alluvial plain. Conservation Biology 10 (5), 1446–1455.
MA DEP, 2001. Chicopee River Basin: 1998 Water Quality Assessment Report. Online at: http://www.state.ma.us/dep/brp/wm/files/projsums.doc.
Marcot, B.G., Holthausen, R.S., Raphael, M.G., Rowland, M.M., Wisdom, M.J., 2001. Using Bayesian belief networks to evaluate fish and wildlife population viability under land management alternatives from an environmental impact statement. Forest Ecology and Management 153, 29–42.
Mardle, S., Pascoe, S., Herrero, L., 2004. Management objective importance in fisheries: an evaluation using the Analytic Hierarchy Process (AHP). Environmental Management 33 (1), 1–11.

Mariotti, M., 1999. Fair bargains: distributive justice and Nash bargaining theory. Review of Economics Studies 66 (3), 733–741.

Martinez-Alier, J., Munda, G., O'Neill, J., 1998. Weak comparability of values as a foundation for ecological economics. Ecological Economics 26, 277–286.

Mcclave, J.T., Benson, P.G., 1988. Statistics for Business and Economics. Macmillan USA.

Messner, F., Zwirner, O., Karkuschke, M., 2006. Participation in multi-criteria decision support for the resolution of a water allocation problem in the Spree River basin. Land Use Policy 23, 63–75.

MWRA (Massachusetts Water Resources Authority), 2003. Quabbin Reservoir and Ware River. Online at: www.mwra.com/04water/html/hist5.htm.

O'Connor, M.F., 1973. The application of multiattribute scaling procedures to the development of indices of water quality. Report 7339, Center for Mathematical Studies in Business and Economics. University of Chicago, Chicago, IL, USA.

O'Connor, M., Faucheux, S., Forger, G., Funtowicz, S., Munda, G., 1996. Emergent complexity and procedural rationality: post-normal science for sustainability. In: Costanza, R., Segura, O., Martinez-Alier, J. (Eds.), Getting down to earth — practical applications of ecological economics. Island Press, Washington, D.C, pp. 223–248.

Pavlikakis, G.E., Tsihrintzis, V.A., 2003. A quantitative method for accounting human opinion, preferences and perceptions in ecosystem management. Journal of Environmental Management 68, 193–205.

Perkins, P.E., 2004. Public participation and ecological valuation. Paper presented at the conference of the International Society for Ecological Economics (ISEE), Montreal, Canada, 10–14 July. Online at: http://www.baciasirmas.org.br/english/doc/article02.pdf.

Pestman, P.K., 1998. Dutch infrastructure policies, public participation and the environment in the 1990s: the politics of interfering logics. In: Coenen, F.H.J.M., Huitema, D., O'Toole, L.J. (Eds.), Participation and the quality of environmental decision making. In: Kluwer Academia Publishers. Dordrecht, Boston, London, pp. 185–202.

Proctor, W., Drechsler, M., 2003. Deliberative multi-criteria evaluation: a case study of recreation and tourism options in Victoria. Paper presented at the Frontiers 2 Conference of the European Society for Ecological Economics, Tenerife, 11–15. February. Online at: http://scholar.google.com/scholar?hl=en&lr=&q=cache:WHnARtKXik4J:www.ecosystemservicesproject.org/html/publications/docs/WP_Jury_final.pdf+deliberative+valuation+ecosystem+services.

Qureshi, M.E., Harrison, S.R., 2001. A decision support process to compare riparian revegetation options in Scheu Creek catchment in North Queensland. Journal of Environmental Management 62, 101–112.

Raiffa, H., 2002. Negotiation analysis: the science and art of collaborative decision making. Belknap Press of Harvard University Press, Cambridge, MA.

Randhir, T.O., O'Connor, R., Penner, P.R., Goodwin, D.W., 2001. A watershed-based land prioritization model for water supply protection. Forest Ecology and Management 143, 47–56.

Renn, O., 1999. A model for an analytic-deliberative process in risk management. Environmental Science and Technology 33 (18), 3049–3055.

Renn, O., 2006. Participatory processes for designing environmental policies. Land Use Policy 23, 34–43.

Renn, O., Webler, T., Wiedemann, P., 1995. A need for discourse on citizen participation: objectives and structure of the book. In: Renn, O., Webler, T., Wiedemann, P. (Eds.), Fairness and competence in citizen participation—evaluating models for environmental discourse. Kluwer Academic Publishers, London, pp. 1–15.

Richardson, M.S., Gatti, R.C., 1999. Prioritizing wetland restoration activity within a Wisconsin watershed using GIS modeling. Journal of Soil and Water Conservation. Third Quarter 537–542.

Ross, H., Buchy, M., Proctor, W., 2002. Laying down the ladder: a typology of public participation in Australian resource management. Australian Journal of Environmental Management 9, 205–217.

Saaty, T.L., 1994. Highlights and critical points in the theory and application of the Analytic Hierarchy Process. European Journal of Operational Research 74 (3), 426–447.

Saaty, ThomasL., 1999. Decision making for leaders, 3rd Edition. RWS Publications, Pittsburgh, PA.

Saaty, T.L., 2001. Deriving the AHP 1–9 scale from first principles. ISAHP 2001. Berne, Switzerland, August 2–4.

Saaty, T.L., 1989. Group decision making and the AHP. In: Golden, B.L., et al. (Ed.), The analytic hierarchy process: applications and studies. Springer-Verlag, Berlin, pp. 59–67.

Sagoff, M., 1998. Aggregation and deliberation in valuing environmental public goods: a look beyond contingent pricing. Ecological Economics 24, 213–230 Feb.–Mar.

Schimpeler, C.C., Baker, N.R., Grecco, W.L., 1969. Criteria weighting: inter-method stability and consistency of preference in an urban planning application. Louisville Metropolitan Comprehensive Transportantion and Development Program, Louisville, KY.

Schoner, B., Wedley, W.C., 2007. Ambigous criteria weights in AHP: consequences and solutions. Decision Sciences 20 (3), 462–475.

Shriver, D.M., Randhir, T.O., 2006. Integrating stakeholder values with multiple attributes to quantify watershed performance. Water Resources Research 42, W08435. doi:10.1029/2005WR004413.

Soma, 2003. How to involve stakeholders in fisheries management: a country case study in Trinidad and Tobago. Marine Policy 27 (1), 47–58.

Stagl, S., 2004. Valuation for sustainable development — the role of multicriteria evaluation. Vierteljahrshefte zur Wirtschaftsforschung 73 (1), 53–62.

Susskind, L. E. 1994. Overview of Developments in Public Participation. In (Eds.), Public Participation in Environmental Decisionmaking (pp. 2–7). ABA Standing Committee on Environmental Law, Washington, DC: Division for Public Services, American Bar Association.

Terán, P., Moreno-Jiménez, J.M., 2008. Group decision making with soft AHP based on the random set view of fuzzy sets. In: Dubois, D., Lubiano, M.A., Prade, H., Gil, M.Á., Grzegorzewski, P., Hryniewicz, O. (Eds.), Soft methods for handling variability and imprecision. Springer-Verlag Berlin Heidelberg, pp. 427–434.

USEPA, 2000. Principles for the ecological restoration of aquatic resources. EPA841-F-00-003. Office of Water (4501F). United States Environmental Protection Agency, Washington, DC. 4 pp.

Vatn, A., Bromley, D.W., 1994. Choices without prices without apologies. Journal of Environmental Economics and Management 26, 129–148.

Webler, T., Kastenholz, H., Renn, O., 1995. Public participation in impact assessment: a social learning perspective. Environmental Impact Assessment Review 15, 443–463.

Weiss, E.N., Rao, V.R., 2007. AHP design issues for large scale systems. Decision Sciences 18 (1), 43–57.

Williams, J.E., Wood, C.A., Dombeck, M.P., 1997. Understanding watershed-scale restoration. Watershed restoration: principles and practices. American Fisheries Society, Bethesda, Maryland, pp. 1–13.