Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Ecological Economics 45 (2003) 297–309

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

ANALYSIS

Multiple-attribute evaluation of ecosystem management for the Missouri River system

Tony Prato *

Center for Agricultural, Resource and Environmental Systems, University of Missouri–Columbia, 212 Mumford Hall, Columbia, MO 65211, USA

Received 22 July 2002; received in revised form 17 February 2003; accepted 26 March 2003

Abstract

Multiple attribute evaluation is used to score and rank five management alternatives for the Missouri River system developed by the U.S. Army Corps of Engineers. Alternatives are characterized by 10 attributes, namely flood control, hydropower, recreation, Missouri River navigation, water supply, fish and wildlife, interior drainage, groundwater, historic properties and Mississippi River navigation. Since preferences for the attributes are unknown, alternatives are compared using four hypothetical attribute-weighting schemes. Utility scores for the alternatives obtained using a linear additive utility function indicate that the modified conservation plan (MCP), which incorporates adaptive management, increased drought conservation measures, changes in Fort Peck dam releases and unbalanced levels in the upper three reservoirs, is preferred to the current water control plan (CWCP) with the neutral, pro-recreation/fish and wildlife, and pro-fish and wildlife weights. MCP ranked above the four Gavins Point (GP) alternatives except with the pro-fish and wildlife weights. CWCP is more preferred than the four GP options with the neutral and pro-agriculture weights and less preferred with the pro-recreation/fish and wildlife and pro-fish and wildlife weights. The GP option with the lowest reduction in summer flow and smallest spring rise (GPA) ranks above the GP option with the highest spring rise and greatest reduction in summer flow (GPB), a spring rise only (GPC) and a lower summer flow only (GPD).

Keywords: Multiple attribute evaluation; Ecosystem management; Missouri River system

1. Introduction

Widespread concern for managing threatened and endangered species has increased environmental programs and policies to protect and restore ecosystems, particularly those managed by federal agencies. Designing effective programs and policies for this purpose requires evaluation and prioritization of management alternatives. This paper demonstrates the use of multiple attribute evaluation in ecosystem management of the Missouri River system. Two multiple attribute evaluation methods are considered: concordance–discordance analysis and utility maximization.

* Present address. Center for Agricultural, Resource and Environmental Systems, University of Missouri–Columbia, 130 Mumford Hall, Columbia, MO 65211, USA. Tel.: +1-573-882-0147; fax: +1-573-884-2199.

E-mail address: pratoa@missouri.edu (T. Prato).

0921-8009/03/$ - see front matter
doi:10.1016/S0921-8009(03)00077-6

The latter is used with a linear utility function and four hypothetical attribute-weighting schemes to score and rank the five management alternatives for the Missouri River system developed by the U.S. Army Corps of Engineers (Corps).

2. Ecosystem management

A desire to reduce the adverse impacts of human activities on ecosystems has led to a shift in management philosophy from extraction and exploitation of natural resources to socially acceptable, economically viable and ecologically sustainable management of ecosystems. This approach, also known as ecosystem management, incorporates larger spatial scales, longer time periods and more variables than commodity-based resource management (Thomas, 1997) and focuses on achieving and sustaining a balance between producing economic goods and services for human consumption and sustaining ecological services (MacKenzie, 1996). The latter include air and water purification, mitigation of floods and drought, detoxification and decomposition of wastes, generation and renewal of soil, maintenance of biodiversity and partial stabilization of climate (Daily, 1997). Successful ecosystem management ensures that the productivity of the whole ecosystem is maintained (Schowalter et al., 1997).

3. Examples of ecosystem management

There are many contemporary examples of ecosystem management in the United States. The Columbia River Basin Fish and Wildlife Program is attempting partial restoration of salmonid fish populations by artificial propagation in fish hatcheries, enhancing fish habitat and improving fish passage at dams and fish hatcheries (Northwest Power Planning Council, 1991). Salmon losses in the basin resulted from destruction and alteration of habitat caused by construction during the period 1930–70 of 19 major dams and 60 smaller hydropower projects that constitute the world's largest hydroelectric power system ($\sim$12,000 MWe). Hydropower development combined with losses in upland habitat due to grazing, timber harvesting and agricultural production reduced fish runs in the basin from their historic high of 10–16 million prior to European settlement to 2.5 million in the late 1970s. In addition, 106 major Northwest Salmon runs have became extinct and 214 runs in Northern California and the Pacific Northwest are at risk of extinction. Economic losses from the decline in Salmon runs are estimated to be $500 million per year (present value losses amount to $13 billion) and 25,000 jobs (Digital Studios, 1997).

In the southeastern United States, the Corps has implemented a plan to restore freshwater ecosystems in and around Everglades National Park in South Florida. The 20-year, multi-billion dollar plan is designed to re-establish South Florida's historic rainwater sheetflow, remove 115 km of canals and 198 km of levees, improve southward flow of water, restrict urban development, purchase drained land and preserve buffer areas on the eastern boundary of the park (National Parks and Conservation Association, 1999).

4. Management of Missouri River system

During the past 60 years, the Corps modified the once free-flowing Missouri River to achieve several objectives including agricultural and urban development, flood control, hydroelectric power, irrigation, navigation, recreation, municipal water supply, water quality and fish and wildlife (Hesse et al., 1988). Thirty-five percent of the 3746 km Missouri River has been impounded and 32% has been channelized (Schlosser, 1987). Construction of dams and reservoirs in the upper basin states has created the nation's largest reservoir system containing 83.8×10^{12} l of storage capacity in six mainstem reservoirs located in Montana, North Dakota, South Dakota and Nebraska (Missouri River Natural Resources Committee, 1998). Channelization, bank stabilization and levee construction along the lower 1176-km stretch of the river between Sioux City, Iowa and St. Louis, Missouri, known as the lower Missouri River, permits navigation and urban-agricultural development of the floodplain (Interagency Floodplain Man-

Fig. 1. Map of Missouri River Basin.

agement Review Committee, 1994). Fig. 1 depicts the Missouri River Basin. The Pick/Sloan Missouri River Basin Program, which was incorporated in the 1944 Flood Control Act (Keenlyne, 1988), and the Missouri River Bank Stabilization and Navigation Project, begun in 1945, authorized structural modifications to the Missouri River. Benefits from these modifications exceed $1 billion annually (U.S. Army Corps of Engineers, 1994).

Structural modifications to the Missouri River have significantly altered fish/wildlife habitat and populations. Channelization of the lower Missouri River has dramatically reduced the size of the meander belt and eliminated vast areas of bottomland forests, sandbars, wetlands and wet prairies. The length of the lower Missouri River has shrunk by 115 km, the width has decreased by two-thirds and riverine shoreline habitat has diminished by 203 km. Urban and agricultural development in the floodplain has displaced almost 143,320 ha of aquatic habitat that once existed in the river's meander belt. Levees constructed for flood protection of agricultural and urban areas have disconnected riverine off-channel habitats and wetlands from the river (Zuerlein et al., 1995). As a result of these modifications, populations of many fish and bird species have declined. Selected species have been listed as endangered or threatened or as species of special concern (Pfleiger and Grace, 1997). Currently, the least tern and pallid sturgeon are the endangered species and the piping plover is the threatened species in the Missouri River.

Several state and federal agencies have developed programs for restoring fish and wildlife habitat in the lower Missouri River. These include the Corps' Missouri River Fish and Wildlife Mitigation Project, the U.S. Fish and Wildlife Service's Boyer Chute National Wildlife Refuge and Big Muddy National Fish and Wildlife Refuge, the Missouri Department of Conservation's Riverlands Project and cost-sharing projects sponsored by the Corps, states and local conservation districts (Missouri River Natural Resources Committee, 1998). Several initiatives have been proposed for habitat restoration, monitoring and research, including the Missouri River Enhancement Program (Vanderpool, 1998), Missouri River Mitigation Program (Kaplan, 1998), and Missouri River Environmental Assessment Program (Missouri River Natural Resources Committee, 1998).

The Corps identified and evaluated the five management alternatives to the current water management plan for the Missouri River system defined in Table 1 (U.S. Army Corps of Engineers, 2001). Guidelines for operating the Mainstem Reservoir system, which consists of six dams in Montana, North Dakota, South Dakota and Nebraska, are described in the Master Manual. While the Corps has authority to revise the Master Manual, it is required by law to seek and consider opinions of stakeholders. The current water control plan (CWCP) establishes guidelines for water releases from the six mainstem reservoirs. Guidelines are used to determine how Missouri River water is stored and released from reservoirs to balance the purposes of the project (flood control, navigation, irrigation, hydropower, water supply, water quality, recreation, and fish and wildlife). The Corps characterized the five alternatives to CWCP as follows: '...[One] alternative, the MCP [modified conservation plan], contains four-... features...: adaptive management, increased drought conservation measures, Fort Peck dam release changes, and unbalancing the upper three reservoirs. The four alternatives referred to as the GP [Gavins Point] options include a fifth feature, Gavins Point dam release changes' (U.S. Army Corps of Engineers, 2001). Release changes for

Table 1
Relative attributes for Missouri River system management alternatives-percentage differences from the CWCP

	Attribute	Alternative				
		MCP[1]	GPA[2]	GPB[3,*]	GPC[4,*]	GPD[5]
1	Flood control ($[6])	−1	−1	−1	−1	−1
2	Hydropower ($)	1	2	2	2	2
3	Recreation ($)	4	4	2	5	2
4	Missouri River navigation ($)	−1	−24	−32	−24	−31
5	Water supply ($)	0	0	0	0	0
6a	Tern and plover (acres)	43	62	74	60	68
6b	Wetland habitat (acres)	1	1	1	1	2
6c	Riparian habitat (acres)	−2	−4	−4	−5	−4
6d	Young-of-year fish (acres)	2	7	7	7	6
6e	Coldwater fish habitat in lakes (acres)	3	9	9	8	9
6f	Coldwater fish habitat in river (acres)	2	7	7	8	7
6g	Warmwater fish habitat in river (acres)	−8	−14	−15	−16	−16
6h	Physical habitat for native fishes (acres)	0	1	1	1	1
7	Interior drainage ($)	−3	−7	−9	−9	−8
8	Groundwater ($)	0	−8	−9	−8	−9
9	Historic properties index ($)	−3	−6	−6	−6	−6
10	Mississippi River navigation ($)	0	0	0	0	0

Source: U.S. Army Corps of Engineers (2001).
[1] Modified conservation plan (spring and summer release of 34.5 kcfs).
[2] Spring rise of 15 kcfs relative to CWCP and summer release of 28.5 kcfs.
[3] Spring rise of 20 kcfs relative to CWCP and summer release as low as 21 kcfs.
[4] Spring rise only of 15 kcfs relative to CWCP.
[5] Lower summer release only of 21 kcfs.
[6] Original metric used to measure the attribute.
* Navigation values could be as high as −86%.

Gavins Point dam and Fort Peck dam were recommended by the U.S. Fish and Wildlife Service to insure that 'Mainstem Reservoir system operations will not likely jeopardize the continued existence of the three listed species or result in the destruction or adverse modifications of critical habitat' (U.S. Army Corps of Engineers, 2001).

The basic premise of adaptive ecosystem management is that 'if human understanding of nature is imperfect, then human interactions with nature (e.g. management actions) should be experimental' (Lee, 1995). Kohm and Franklin (1997) point out that 'adaptive management is the only logical approach under the circumstances of uncertainty and the continued accumulation of knowledge'. Adaptive ecosystem management treats management actions as experiments for acquiring information about ecological responses to those actions. Experimental results provide a basis for determining whether or not a particular management action is ecologically sustainable. Drought conservation measures allow more water to be stored in the three upper reservoirs (Ft. Peck, Sakakawea and Oahe) during extended drought periods, which reduces the length of the navigation service. Increased releases (23 kcfs for 3 weeks) would be made from Ft. Peck dam in mid-May through June approximately every other year to trigger pallid sturgeon spawning.

The amount of water in the upper three reservoirs is balanced with CWCP. This means the effects of above or below normal system inflows are shared equally among the three reservoirs. Unbalancing the upper three reservoirs involves lowering one of the three reservoirs approximately 3 feet on a 3-year cycle. When a reservoir is lowered, more vegetation grows along its perimeter, which provides sandbar habitat for interior least tern and piping plover. When a reservoir is raised, the sandbar area is inundated providing improved habitat for spawning and better protection (hiding areas) for fish. Movement of water among the three reservoirs is also expected to benefit species in the intervening river reaches by triggering the spawning of pallid sturgeon and scouring vegetation on sandbars making them more suitable habitat for nesting least terns and plovers.

The four GP options, designated GPA, GPB, GPC and GPD, incorporate the same four features as the MCP option plus a range of releases from Gavins point dam designed to improve habitat for pallid sturgeon, interior least tern and piping plover. They consist of a spring rise (increased spring releases) on average once every 3 years between May 1 and June 15 and a summer low (decreased summer releases) every year as conditions allow. A spring rise provides a spawning cue for pallid sturgeon and lower summer flows expose more sandbars for tern and plover nesting and creates shallow water habitat for young pallid sturgeon. GPA has the lowest spring rise above full navigation releases (15 kcfs) and the highest summer releases (28.5 kcfs). GPB has the highest spring rise (20 kcfs) and lowest summer releases (21 kcfs). The GPC and GPD alternatives involve a higher spring rise only and a lower summer release only, respectively. All releases from Gavins Point dam would be based on adaptive management.

5. Multiple attribute evaluation

Multiple attribute evaluation allows decision-makers and stakeholders to rank management alternatives based on their preferences for the attributes of alternatives. The most preferred management alternative is the one that provides the most desirable combination of attributes. Multiple attribute evaluation has been proposed and/or used in water resource systems analysis (Haimes and Hall, 1974), environmental management (Backus et al., 1982 Janssen, 1992), food security (Haettenschwiler, 1994), forest management (Kangas, 1994 Kangas and Kuusipalo, 1993 Pfleiger and Grace, 1997), farm-environmental management (Xu et al., 1995), protected area management (Anselin et al., 1989 Gehlbach, 1975 Sargent and Brande, 1976 Smith, 1987 Smith and Theberge, 1986), regional water quality analysis (Makowski et al., 1995), management of ecosystems (Prato et al., 1996a Prato, 1999a), wildlife management (Prato et al., 1996b) and soil and water resource management (Prato, 1998).

There are two primary advantages of using multiple attribute evaluation to compare management alternatives for the Missouri River system. First, multiple attribute evaluation does not require measuring all the attributes in monetary terms as does benefit-cost analysis. This advantage is significant in the present application because the eight fish and wildlife sub-attributes are not measured in dollar terms. The monetary value of attributes is estimated using techniques such as contingent valuation. This survey method estimates non-use values based on an individual's willingness-to-pay to improve environmental quality or willingness-to-accept compensation to avoid environmental damages. For example, contingent valuation was used to evaluate the public's willingness-to-pay to avoid the ecological damages that occurred in 1989 from the Exxon Valdez oil spill in Prince William Sound, Alaska. It is not feasible to use contingent valuation methods for large and complex ecosystems like the Missouri River system.

Second, multiple attribute evaluation facilitates collaborative decision-making for public goods (Joubert et al., 1997) by allowing stakeholders to compare alternatives based on their preferences for attributes rather than the traditional top-down approach to management. The latter is unappealing because it often results in recommendations that lack practical significance and broad-based community support. Lee and Stankey (1992) observe, 'Large-scale (regional) ecological systems can be most effectively regulated by small-scale (local) social organizations'. Naiman et al. (1997) indicate '…watershed management demands unparalleled cooperation between citizens, industry, governmental agencies, private institutions, and academic organizations'. Local social organizations and cooperation require decentralized decision-making.

A general framework for multiple attribute evaluation is illustrated in Fig. 2. The framework requires identifying management objectives and alternatives, attributes of objectives, and weights for objectives and attributes. Alternatives are unique to the particular ecosystem and management issues being addressed. Weights represent the decision-maker's preferences for objectives or attributes. Determination of weights is simplified by using a hierarchical approach in which weights are first assigned to objectives and then the weight for each objective is allocated to the attributes that describe that objective as illustrated in Fig. 3. The example has three objectives: economic viability, social acceptability and ecological health. Attributes are employment and output for the economic viability objective, recreational opportunities and fairness for the social acceptability objective and species richness and biodiversity for the ecological health objective. Attribute weights and values are combined in a utility function that is used to score the alternatives. Scores are used to rank alternatives. Since decision-makers usually have different weights for attributes, the ranking of alternatives is likely to vary across decision-makers. The highest ranked alternative is the best one.

5.1. Weighting methods and ranking algorithms

Several methods are available for ranking alternatives. Two methods are examined here: concordance–discordance analysis and utility maximization. Concordance–discordance analysis ranks alternatives based on concordance (degree of similarity) and discordance (degree of dissimilarity) indices for each pair of alternatives. If there are n alternatives, then the total number of pairs of alternatives is $n!/(n-2)!$. The concordance index is the following standardized sum of attribute weights for which the ith alternative is preferred to i'th alternative:

$$c_{ii'} = \frac{\sum_{j \in C(i,i')} w_j}{\sum_{j=1}^{m} w_j}, \tag{1}$$

where w_j is the weight for the jth attribute, $C(i, i')$ is the set of alternatives for which the ith alternative is preferred or equivalent to the i'th alternative, and m is the number of attributes.

The discordance index is obtained by finding the maximum difference in standardized attributes for which the ith alternative performs better than the i'th alternative over all pairs of alternatives. The discordance index is:

$$d_{ii'} = \max_{j \in D(i,i')} (s_{i'j} - s_{ij}) \tag{2}$$

where s_{ij} is the jth standardized attribute for the ith alternative, $s_{i'j}$ is the jth standardized attribute for the i'th alternative, and $D(i, i')$ is the set of alternatives for which the ith alternative is preferred to the i'th alternative.

The overall performance measure for an alternative is determined from a net concordance dominance value (c_i) and a net discordance dominance value (d_i) (Van Deflt and Nijkamp,

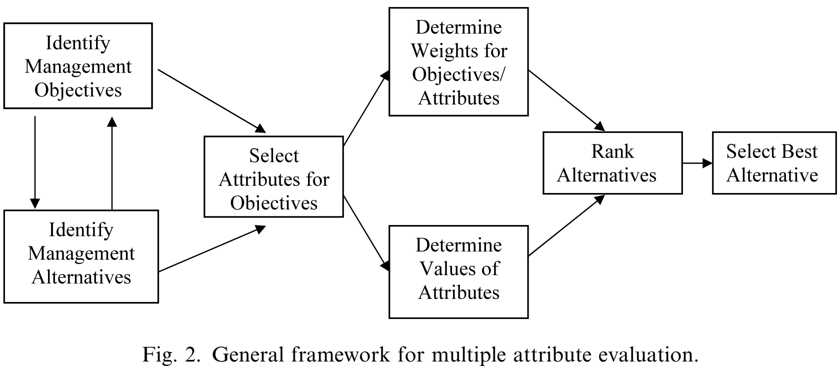

Fig. 2. General framework for multiple attribute evaluation.

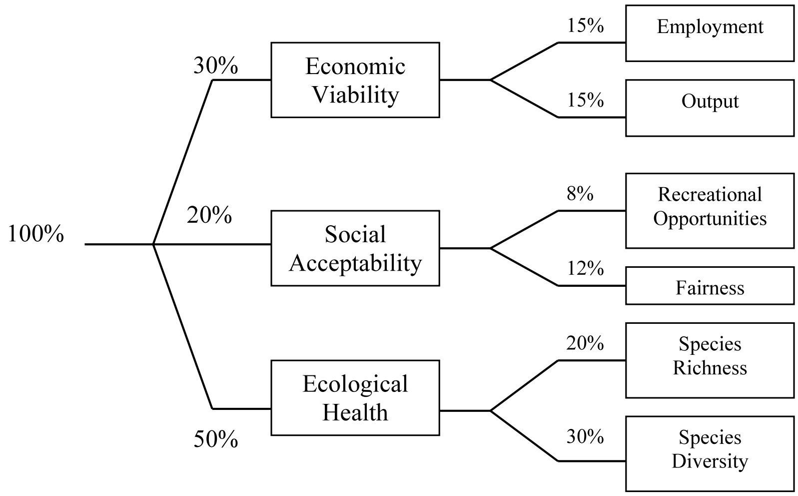

Fig. 3. Hierarchical approach to determining weights.

1977). A high net concordance dominance value and a low net discordance dominance value increase the rank of an alternative. Net concordance and net discordance dominance values are, respectively:

$$c_i = \sum_{i=1}^{n} c_{ii'} - c_{i'i} \tag{3}$$

$$d_i = \sum_{i=1}^{n} d_{ii'} - d_{i'i} \tag{4}$$

There are several ways to rank alternatives based on c_i and d_i. Ozelkan and Duckstein (1996) suggested the overall net dominance score, namely $o_i = c_i - d_i$. Unlike the ELECTRE method (Roy, 1972), the overall net dominance score does not require a decision-maker to specify concordance and discordance thresholds. This is an advantage because most decision-makers are unfamiliar with these concepts.

The second multiple attribute evaluation method and the one used here is utility maximization, which involves maximizing a multiple attribute utility function. Since the ranking of alternatives based on a utility function is likely to be biased when attributes are measured in different units, attributes are standardized. Interval standardization is done as follows:

$$s_{ij} = \frac{x_{ij} - \min_j x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} \quad \text{for positive attributes where more is better} \tag{5}$$

$$s_{ij} = \frac{\max_j x_{ij} - x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} \quad \text{for negative attributes where less is better} \tag{6}$$

x_{ij} is the raw value and s_{ij} is the standardized value of the jth attribute for the ith alternative.

Utility scores for alternatives can be calculated using either a linear Eq. (7) or non-linear Eq. (8) additive utility function, as follows:

$$v_i = \sum_{j=1}^{m} w_j s_{ij} \quad (i = 1, \ldots, n) \tag{7}$$

$$v_i = \sum_{j=1}^{m} w_j (s_{ij})^{1/2} \quad (i = 1, \ldots, n) \tag{8}$$

where m is the number of attributes, w_j is the weight for the jth attribute, $0 \leq w_j \leq 1$ and $\Sigma_{j=1}^{m} w_j = 1$. An additive utility function, like the ones given in Eqs. (7) and (8), assumes that the decision-maker is risk neutral (Prato, 1999b). Although non-additive utility functions allow for interdependence between attributes, they are more difficult to estimate than additive utilty functions. For this reason, this study uses an additive utility function. The linear utility function (Eq. (7)) implies constant marginal utility of attributes, namely the utility received from an additional unit of the attribute is independent of the amount of the attribute. The non-linear utility function (Eq. (8)) implies the attributes are subject to diminishing marginal utility, which means the utility obtained from an additional unit of the attribute decreases with more of the attribute. While a non-linear utility function is consistent with the law of diminishing marginal utility and a linear utility function is not, the non-linear function was not used in this application because some of the relative attributes are negative and the square root of a negative number is undefined.

5.2. Estimation of attributes

Multiple attribute evaluation requires estimation of the values of attributes for different alternatives. This is typically done using expert-based methods, such as the Delphi method (Dalkey, 1967 Seaver, 1976) or the Nominal Group Technique (Seaver, 1976), or simulation methods. For example, Fausch et al. (1988) used stream habitat models to simulate responses of stream-dwelling organisms to changes in siltation and chemical pollution. Berkman and Rabeni (1987) Rabeni and Smale (1995) estimated empirical relationships between fish/invertebrate communities and siltation levels, and Smale and Rabeni (1991) estimated the relationship between fish communities and dissolved oxygen and summer temperatures. Ecological effects of proximate habitat conditions in a stream can be estimated by employing an index of biological integrity to assess biological responses to one or more environmental variables (Karr et al., 1986).

In larger ecosystems, the CENTURY model has been used to simulate the effects of changes in climate and management on net primary production, nutrient availability and carbon/nitrogen fluxes (Parton et al., 1995). Oijima and Parton (1996) found that over the past 100 years, crop yields in the Great Plains increased whereas soil organic matter content and mineralization rates for soil nitrogen decreased based on the CENTURY model. Parton et al. (1995) Donigian et al. (1995) concluded that alternative management systems in the Corn Belt would improve carbon storage in soils while causing only minor losses in corn yield.

The Corps evaluated the five alternatives using 10 primary attributes: flood control, hydropower, recreation, Missouri River navigation, water supply, fish and wildlife, interior drainage, groundwater, preservation of historic properties and maintaining adequate navigation flows for the Mississippi River. Since some of the attributes are in monetary terms and others are not, the Corps compared the management alternatives in relative terms. In particular, the value of each attribute for the five alternatives to CWCP was expressed as a percentage deviation from the corresponding value of the attribute for CWCP (Table 1). Consider how to calculate the relative attributes for hydropower. Estimated average annual hydropower benefits for the 1898–1997 period were \$741.52 million for CWCP, \$747.42 million for MCP, \$758.76 million for GPA, \$754.83 million for GPB, \$758.01 million for GPC and \$755.37 million for GPD (U.S. Army Corps of Engineers, 2001). Compared to CWCP, hydropower benefits are approximately 1% higher for MCP and 2% higher for the four GP options as shown in Table 1. Relative attributes for the five management alternatives range from −32% for

Missouri River navigation to 74% for tern and plover habitat with GPB (Table 1). A negative value indicates the attribute is lower and a positive value indicates the attribute is higher with the alternative than with CWCP. Since percentages are already standardized, it was not necessary to standardize the attributes using Eq. (5) or (6).

5.3. Attribute weights

Attribute weights for individuals are typically estimated using fixed-point scoring, paired comparisons (Saaty, 1987) and judgment analysis (Cooksey, 1996). Attribute weights for a group of individuals can be estimated several ways. First, a consensus-based approach brings stakeholders together for the purpose of reaching agreement on a compromise set of weights. It is not feasible to use this approach in the Missouri River system because of the large and diverse number of stakeholders. However, it is feasible to reach consensus on weights for relatively small groups of stakeholders. Second, majority-based decision-making requires stakeholders to vote on the set of weights. The set of weights receiving a majority of the votes is used to rank alternatives. Voting has not been used to determine attribute weights for alternatives developed in an environmental impact statement, although it could be done. Third, public opinions on the most preferred set of attribute weights can be solicited during the public comment period. The most preferred weights are then used to calculate utility scores, which are then used to rank the alternatives.

There is no prior information about the weights stakeholders place on the 10 primary attributes. For this reason, the analysis is based on the four hypothetical attribute-weighing schemes given in Table 2. The neutral scheme (1) assigns equal weights to the 10 primary attributes with equal weights to the eight fish and wildlife sub-attributes. The pro-recreation/fish and wildlife scheme (2) assigns 30% weight to the recreation attribute, 30% equally divided among the eight fish and wildlife sub-attributes, and the remaining 40% weight equally divided among the remaining eight primary attributes. Scheme 2 places high importance on recreation and fish and wildlife. The pro-fish and wildlife scheme (3) assigns 60% weight to the primary fish and wildlife attribute and 40% weight to each of the remaining nine attributes. Of the 60% weight assigned to the fish and wildlife attribute, 60% is assigned to the tern and plover habitat sub-attribute and the other 40% is divided equally among the remaining seven fish and wildlife sub-attributes. Scheme 3 places high importance on protection of endangered species. The pro-agriculture scheme (4) assigns 20% weight each to Missouri River navigation, interior drainage and groundwater attributes, divides the remaining 40% weight equally among the remaining seven primary attributes, and assigns equal weights to the eight fish and wildlife sub-attributes. Scheme 4 places high importance on attributes that influence agriculture.

6. Results and discussion

Relative utility scores for the five management alternatives are calculated by substituting the relative attributes for an alternative given in Table 1 and hypothetical attribute weights given in Table 2 into the utility function (Eq. (7)). Relative utility scores and ranks are reported in Table 3. A positive score implies the alternative is preferred to CWCP and a negative score implies CWCP is preferred to the alternative.

Relative utility scores indicate MCP with the neutral scheme, all alternatives with the pro-recreation/fish and wildlife scheme and pro-fish and wildlife scheme, and none of the alternatives with the pro-agriculture scheme are preferred to CWCP. CWCP is preferred to all of the alternatives with the pro-agriculture scheme and all of the GP options with the neutral scheme. MCP ranks first with schemes 1, 2 and 4, and fifth with scheme 3. GPA, which is the GP option with the lowest spring rise and highest summer flow, ranks second or third. GPB, which has the highest spring rise and lowest summer flow, is ranked first with scheme 3 and last with schemes 1, 2 and 4. GPC, which has a spring rise but no reduction in summer flow, is ranked second with scheme 2, third with schemes 1 and 4, and fourth with scheme 3. GPD, which has a lower summer release than CWCP but

Table 2
Four hypothetical weighting schemes for attributes of management alternatives for the Missouri River system

Attribute		Scheme			
		1[1]	2[2]	3[3]	4[4]
1	Flood control ($)	0.100	0.050	0.044	0.057
2	Hydropower ($)	0.100	0.050	0.044	0.057
3	Recreation ($)	0.100	0.300	0.044	0.057
4	Missouri River navigation ($)	0.100	0.050	0.044	0.200
5	Water supply ($)	0.100	0.050	0.044	0.057
6a	Tern and plover habitat (acres)	0.013	0.038	0.360	0.007
6b	Wetland habitat (acres)	0.013	0.038	0.034	0.007
6c	Riparian habitat (acres)	0.013	0.038	0.034	0.007
6d	Young-of-year fish (production)	0.013	0.038	0.034	0.007
6e	Coldwater fish habitat/lakes (MAF)	0.013	0.038	0.034	0.007
6f	Coldwater fish habitat/river (miles)	0.013	0.038	0.034	0.007
6g	Warmwater fish habitat/river (miles)	0.013	0.038	0.034	0.007
6h	Physical habitat/native fishes (index)	0.013	0.038	0.034	0.007
7	Interior drainage ($)	0.100	0.050	0.044	0.200
8	Groundwater ($)	0.100	0.050	0.044	0.200
9	Historic properties index ($)	0.100	0.050	0.044	0.057
10	Mississippi River navigation ($)	0.100	0.050	0.044	0.057

Note: Attributes 6a through 6h constitute the fish and wildlife attribute.
[1] Neutral.
[2] Pro-recreation/fish and wildlife.
[3] Pro-fish and wildlife.
[4] Pro-agriculture.

Table 3
Relative utility scores and ranks for five Missouri River system management alternatives with four weighting schemes [1]

Alternative	Scheme							
	1[1]		2[2]		3[3]		4[4]	
	Score[5]	Rank	Score	Rank	Score	Rank	Score	Rank
MCP[6]	0.213	1	2.388	1	15.279	5	−0.451	1
GPA[7]	−3.138	2	1.588	3	20.800	3	−7.365	2
GPB[8]	−4.300	5	0.850	5	24.514	1	−9.601	5
GPC[9]	−3.300	3	1.600	2	19.933	4	−7.744	3
GPD[10]	−4.188	4	0.688	4	22.407	2	−9.251	4

[1] Neutral.
[2] Pro-recreation/fish and wildlife.
[3] Pro-fish and wildlife.
[4] Pro-agriculture.
[5] Plus (+) indicates the alternative has a higher utility value and minus (−) indicates a lower utility score than CWCP.
[6] Modified conservation plan (spring and summer release of 34.5 kcfs).
[7] Spring rise of 15 kcfs relative to CWCP and summer release of 28.5 kcfs.
[8] Spring rise of 20 kcfs relative to CWCP and summer release as low as 21 kcfs.
[9] Spring rise only of 15 kcfs relative to CWCP.
[10] Lower summer release only of 21 kcfs.

no spring rise, ranks second with scheme 3 and fourth with schemes 1, 2 and 4. In summary, MCP ranks higher than CWCP except with scheme 4 (pro-agriculture) and higher than the GP alternatives except with scheme 3 (pro-fish and wildlife). In addition, GPB, which exhibits the greatest departure from CWCP is ranked last except with the pro-fish and wildlife scheme. The five alternatives were compared to CWCP based on their average relative utility score across the four attribute weighting schemes. In order of magnitude, the average utility scores are: 4.4 for MCP, 3.0 for GPA, 2.9 for GPB, 2.6 for GPC, and 2.4 for GPD. This comparison indicates that MCP ranks first, GPA ranks second, GPB ranks third, GPC ranks fourth and GPD ranks last. Other weighting schemes could result in different rankings.

7. Conclusion

Ecosystem management of natural resource systems necessitates comparison of management alternatives. Since the fish and wildlife impacts of water management alternatives for the Missouri River system have not been evaluated in monetary terms, it is not possible to compare those alternatives using benefit–cost analysis. Therefore, the five river management alternatives identified by the Corps were compared to the current management plan using multiple attribute evaluation. Multiple attribute evaluation is a bottom-up approach that avoids some of the ethical, theoretical and practical shortcomings of the net present value criterion used in cost–benefit analysis.

A linear additive utility function was used to score and rank five management alternatives relative to CWCP. This form of the utility function assumes constant marginal utility of attributes, utility independence of attributes and a risk neutral decision-maker. Relative utility scores for the five alternatives were calculated based on the attribute values estimated by the Corps and four hypothetical attribute-weighting schemes.

Results show that MCP, which incorporates adaptive management, increased drought conservation measures, changes in Fort Peck dam releases and unbalanced levels in the upper three reservoirs, ranks higher than CWCP with the neutral, pro-recreation/fish and wildlife, and pro-fish and wildlife weighting schemes. MCP ranks above all four GP alternatives except with the pro-fish and wildlife weights. CWCP ranks higher than the four GP options with the neutral and pro-agriculture weighting schemes and below the four GP options with the pro-recreation/fish and wildlife and pro-fish and wildlife weights. Averaged over the four weighting schemes examined here, the GP option with the least reduction in summer flow and lowest spring rise (GPA) ranks above the GP options with the highest spring rise and greatest reduction in summer flow (GPB), a spring rise only (GPC) and a lower summer flow only (GPD).

Multiple attribute evaluation provides a viable way to evaluate and compare alternatives that have attributes not measured in monetary terms. This advantage comes at a cost, however. Unlike benefit-cost analysis it requires specifying the form of the utility function and estimating attribute weights. On the other hand, determining attribute weights provides a pro-active way to get stakeholders involved in the decision-making process.

References

Anselin, A., Meire, P.M., Anselin, L., 1989. Multicriteria techniques in ecological evaluation: an example using the analytic hierarchy process. Biol. Conserv. 49, 215–229.

Backus, G.J., Stillwell, W.G., Latter, S.M., Wallerstein, M.C., 1982. Decision making with applications for environmental management. Environ. Manag. 6, 493–504.

Berkman, H.E., Rabeni, C.F., 1987. Effect of siltation on stream fish communities. Environ. Biol. Fishes 18, 285–294.

Coolsey, R.W., 1996. Judgment Analysis: Theory, Methods and Applications. Academic Press, Sydney, Australia, 407 pp.

Daily, G.C., 1997. Introduction: what are ecosystem services? In: Daily, G.C. (Ed.), Nature: Societal Dependence on Natural Ecosystems Services. Island Press, Washington, DC, pp. 1–10.

Dalkey, N.C., 1967. Second Symposium on Long Range Forecasting and Planning. Alamogordo, NM, Report P-3704, The Rand Corporation, Santa Monica, CA, October 11–12.

Digital Studios, 1997. Task Force Environmental Investigations Kit: Salmon vs. Hydropower, Aptos, CA.

Donigian, A.S., Jr., Patwardham, A.S., Jackson, R.B., IV, Barnwell, T.O., Jr., Weinrich, K.B., Rowell, L., 1995. Modeling the impacts of agricultural management practices on soil C in the Central U.S. In: La, R., Kimble, J., Levine, E., Steward, B.A. (Eds.), Soil Management and Greenhouse Effects: Advances in Soil Science. CRC Press, Boca Raton, FL, pp. 121–145.

K.D., Fausch, Hawkes, C.L., Parsons, M.G., 1988. Models that Predict Standing Crop of Stream Fish from Habitat Variables: 1950–85. General Technical Report PNW-213, U.S. Forest Service, Washington, DC.

Gehlbach, F.R., 1975. Investigation, evaluation, and priority ranking of natural areas. Biol. Conserv. 8, 79–88.

Haettenschwiler, P., 1994. Decision Support Systems Applied to Swiss Federal Security Policy and Food Supply. International Institute of Applied Systems Analysis Workshop, Laxenburg, Austria.

Haimes, Y.Y., Hall, W.A., 1974. Multiobjectives in water resource systems: the surrogate tradeoff method. Water Resour. Res. 10, 615–624.

Hesse, L.W., Wolfe, C.W., Cole, N.C., 1988. Some aspects of energy flow in the Missouri River ecosystem and a rationale for recovery. In: Benson N.G. (Ed.), The Missouri River, The Resources, Their Uses and Values. Special Publication No. 8, North Central Division, American Fisheries Society.

Interagency Floodplain Management Review Committee, 1994. Sharing the Challenge, Floodplain Management in the 21st Century, Part 5, SAST Report, Washington, DC.

Janssen, R., 1992. Multiobjective Decision Making for Environmental Management. Kluwer Academic Publishers, The Netherlands, 248 pp.

Joubert, A.R., Leiman, A., de Klerk, H.M., Katua, S., Aggenbach, J.C., 1997. Fynbos (fine bush) vegetation and the supply of water: a comparison of multi-criteria decision analysis. Ecol. Econ. 22, 123–140.

Kangas, J., 1994. An approach to public participation in strategic forest management planning. Forest Ecol. Manag. 70, 75–88.

Kangas, J., Kuusipalo, J., 1993. Integrating biodiversity into forest management planning and decision-making. Forest Ecol. Manag. 61, 1–15.

Kaplan, D., 1998. Senate Committee Approves Bond Bill. Missouri Monitor, vol. 1, no. 3, August.

Karr, J.R., Fausch, K.D., Andermeier, P.L., Yant P.R., Schlosser I.J., 1986. Assessing Biological Integrity in Running Waters: A Method and its Rational. Illinois Natural History Survey, Special Publication 5, Champaign, IL.

Keenlyne, K.D., 1988. Economic development from Lewis and Clark to Pick-Sloan. In: Benson N.G. (Ed.), The Missouri River, The Resources, Their Uses and Values. Special Publication No. 8, North Central Division, American Fisheries Society.

Kohm, K.A., Franklin, J.F., 1997. Introduction. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating Forestry for the 21st Century: the Science of Ecosystem Management. Island Press, Washington, DC, pp. 1–5.

Lee, K.N., 1995. Deliberately seeking sustainability in the Columbia River Basin. In: Gunderson, L.H., Holling, C.S., Light, S.S. (Eds.), Barriers and Bridges to the Renewal of Ecosystems and Institutions. Columbia University Press, New York, pp. 214–238..

Lee, R.G., Stankey, G.S., 1992. Major issues associated with managing watershed resources. In: Adams P.W., Atkinson W.A. (Eds.), Evaluating Institutional Arrangements for Large Watersheds and River Basins. Oregon State University, Corvallis, OR, pp. 30–37.

MacKenzie, S.H., 1996. Integrated Resource Planning and Management: The Ecosystem Approach in the Great Lakes Basin. Island Press, Washington, DC.

Makowski, M., Somlyody L., Watkins, D., 1995. Multiple Criteria Analysis for Regional Water Quality Management: the Nitra River Case. Working Paper WP-95-022, International Institute of Applied Systems Analysis, Laxenburg, Austria.

Missouri River Natural Resources Committee in partnership with the U.S. Geological Survey, Biological Resources Division, 1998. Missouri River Environmental Assessment Program.

Naiman, R.J., Bisson, P.A., Lee, R.G., Turner, M.G., 1997. Approaches to management at the watershed scale. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating Forestry for the 21st Century: The Science of Ecosystem Management. Island Press, Washington, DC, pp. 239–253.

National Parks and Conservation Association, 1999. River of Grass Ready to Heal. National Parks, vol. 7, no. 1–2, January/February.

Northwest Power Planning Council, 1991. Columbia River Basin Fish and Wildlife Program. Northwest Power Planning Council, Portland, OR.

Oijima, D.S., Parton, W.J., 1996. Integrated Approaches to Land Use Analysis, Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, NM, January 21–25.

Ozelkan, E.C., Duckstein, L., 1996. Analyzing water resources alternatives and handling criteria by multi criterion decision techniques. Environ. Manag. 48, 69–96.

Parton, W.J., Oijima, D.S., Schimel, D.S., 1995. Models to evaluate soil matter storage and dynamics. In: Carter, M.R., Stewart, B.A. (Eds.), Structure and Organic Matter Storage in Agricultural Soils. CRC Press, Boca Raton, FL.

Pfleiger, W.L., Grace, T.B., 1997. Changes in the two forms of the simple additive weighted utility function were used to score and rank seven water management alternatives for the Missouri River System. Fish Fauna of the Lower Missouri River, 1940–83. In: Matthews, W.J., Heins, D.C. (Eds.), Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, OK, pp. 166–177.

Prato, T., Fulcher, C., Wu, S., Ma, J., 1996a. Multiple-objective decision making for agroecosystem management. Agric. Res. Econ. Rev. 25, 200–212.

Prato, T., Fulcher, C., Zhou, Y., 1996. Integrated Resource Management Using a Decision Support System. Southern

African Wildlife Management Association Conference, Sustainable Use of Wildlife, University of Cape Town, South Africa, p. 48, April 9–11.

Prato, T., 1998. Protecting soil and water resources through multi-objective decision making. In: El-Swaify, S.A., Yakowitz, D.S. (Eds.), Multiple Objective Decision Making for Land, Water and Environmental Management. St. Lucie Press, Delray Beach, FL, pp. 385–394.

Prato, T., 1999a. Multiple attribute decision analysis for ecosystem management. Ecol. Econ. 30, 207–222.

Prato, T., 1999b. Risk-based multiattribute decision making in property and watershed management. Nat. Resour. Model. 12, 307–334.

Rabeni, C.F., Smale, M.A., 1995. Effects of siltation on stream fishes and potential mitigating role of the buffering riparian zone. Hydrobiologia 303, 211–219.

Roy, B., 1972. Decision avec criteres multiples. Metro 11, 121–151.

Saaty, R.W., 1987. The analytic hierarchy process: what is it and how it is used? Math. Model. 9, 161–176.

Sargent, F.O., Brande, J.H., 1976. Classifying and evaluating unique natural areas for planning purposes. J. Soil Water Conserv., 113–116 (May–June).

Schlosser, I.J., 1987. A conceptual framework for fish communities in small warmwater streams. In: Matthews, W.J., Heins, D.C. (Eds.), Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, OK.

Schowalter, T., Hansen, E., Molina, R., Zhang, Y., 1997. Integrating the ecological roles of phytophagous insects, plant pathogens, and mycorrihzae in managed forests. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating Forestry for the 21st Century: The Science of Ecosystem Management. Island Press, Washington, DC, pp. 171–189.

Seaver, D.A., 1976. Assessment of Group Preferences and Group Uncertainty for Decision-Making. University of Southern California Social Science Research Institute, Research Report 76–4, 1–61.

Smale, M.A., Rabeni, C.F., 1991. The Effects of Special Area Land Treatment (SALT) Agricultural Management Practices on the Biological Health of Headwater Streams. A Final Report submitted to the Missouri Department of Natural Resources, Water Quality Division, Jefferson City, MO.

Smith, P.G.R., 1987. Evaluating natural areas using multiple criteria: theory and practice. Environ. Manag. 11, 447–460.

Smith, P.G.R., Theberge, J.B., 1986. A review of criteria for evaluating natural areas. Environ. Manag. 10, 715–734.

Thomas, J.W., 1997. Foreword. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating Forestry for the 21st Century: the Science of Ecosystem Management. Island Press, Washington, DC, pp. ix–xii.

U.S. Army Corps of Engineers, 1994. Master water control manual review and update study. vol. 6C: Economic Studies, Recreation Economics, Omaha, NB.

U.S. Army Corps of Engineers, 2001. Summary: Missouri River Revised Draft Environmental Impact Statement, Master Water Control Manual, Review and Update. Northwestern Division, Omaha, NB.

Van Deflt, A., Nijkamp, P., 1977. Multi-Criteria Analysis and Regional Decision-Making. Kluwer Academic Publishers, The Hague, Netherlands, 140 pp.

Vanderpool, G., 1998. Acquisition will Reduce Flood Losses, aid Wildlife. Missouri Monitor, vol. 1, no. 5, October.

Xu, F., Prato, T., Ma, J.C., 1995. A farm-level case study of sustainable agricultural production. J. Soil Water Conserv. 50, 39–44.

Zuerlein, G., Mestl, G., Brohman, M., 1995. The Missouri River: A Crown Jewel in Need. Nebraska Game and Parks Commission, Lincoln, NE.