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Participatory floodplain management in the Red River Basin, Canada

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Abstract

Floodplain management is a subject in which everyone in the floodplain is a stakeholder. Real participation only takes place when stakeholders are part of the decision-making process. This can occur directly when local communities come together to make floodplain management choices or if democratically elected or otherwise accountable agencies or groups can represent stakeholders. Real participation is more than consultation and requires that stakeholders at all levels of the social structure have an impact on decisions at different levels of floodplain management. A participatory approach is the only means for achieving long-lasting consensus and common agreement. However, for this to occur, stakeholders and officials from water management agencies have to recognize that the sustainability of floodplain management decisions is a common problem and that all parties are going to have to sacrifice some desires for the common good. There is common responsibility for making participation possible. This involves (a) the creation of mechanisms for stakeholder consultation at various scales (from local, over watershed to national) and (b) the creation of participatory capacity, particularly amongst marginalized social groups. This may include awareness raising, confidence building and education, as well as the provision of the economic resources needed to facilitate participation and the establishment of good and transparent sources of information.

This work focuses on the methodology for stakeholder participation in floodplain management. Floodplain management problems are characterized by multiple objectives and large number of stakeholders. The solution methodologies adapted for multi-criteria multi participant decision problems are generally based on aggregation of decisions obtained for individual decision makers. This approach seems somewhat inadequate when the number of stakeholders is very large. We have developed a methodology to include the views of multiple stakeholders using fuzzy set theory and fuzzy logic. Three possible different response types: scale (crisp), linguistic (fuzzy), and conditional (fuzzy) are analyzed to obtain the resultant input by using Fuzzy Expected Value. Fuzzy Expected Value input is used with the multi-criteria decision-making tool named Fuzzy Compromise Programming.

The methodology has been applied to floodplain management in the Red River Basin, Canada that faces periodical flooding. We have demonstrated that the empowerment of stakeholders can improve the floodplain management process and provide decisions acceptable to a wider group of stakeholders.

Keywords: Floodplain management; Multiple stakeholders; Multiple criteria decision-making; Fuzzy set theory; Compromise programming

1. Introduction

Floodplain management in general comprises of different water resources activities aimed at reducing potential harmful impact of floods on people, environment and economy of a region. Sustainable floodplain management decision-making requires integrated consideration of economic, ecological and social consequences of disastrous flood events. While economic consideration gets priority in traditional approach to floodplain decision-making, empowerment of stakeholders is an issue that demands increased attention. Floodplain management activities (i.e. disaster mitigation, preparedness and emergency management) may be designed and achieved without the direct participation of stakeholders. However, they cannot be implemented without them (Affeltranger, 2001). Local communities directly, or democratically elected or otherwise accountable agencies or groups that can represent them should get together to make floodplain management choices.

The Red River flood of 1997 was the worst on record in many locations; it caused widespread damage throughout the

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Red River valley. The governments of Canada and the United States have agreed that steps must be taken to reduce the impact of future flooding. In June of 1997, they asked the International Joint Commission (IJC) to analyze the causes and effects of the Red River flood of 1997. The IJC appointed the International Red River Basin Task Force to examine a range of alternatives to prevent or reduce future flood damage.

The Task Force's studies provide insights and advice for decision-makers on reducing or preventing devastation such as occurred during the 1997 flood. The Task Force's work also provided useful data and tools for those who plan, design, and implement flood reduction policies, programs and projects. These data and tools provide those with operational responsibilities a much greater ability to forecast flood events and to carry out efficiently the emergency measures to save lives and property.

The Task Force dealt with the question as to what collaborative and integrated problem solving mechanisms are required in the Red River basin. The aim was to enhance coordination and cooperation throughout the entire basin long after the Task Force has finished its assignment. In summary, the Task Force has defined specific objectives for its investigations as: (i) develop and recommend a range of alternatives to prevent or reduce future flood damages, (ii) improve tools for planning and decision-making, and (iii) facilitate integrated floodplain management in the basin. The Task Force's final report (International Joint Commission, 2000) made recommendations on policy, operations, and research issues. The IJC used the final report as the basis for public hearings in the basin prior to the submission of its report to governments.

Public participation was an important part of the process. Following the distribution of the Interim Report, the IJC and the Task Force conducted a series of public meetings throughout the basin in February and October of 1998. The results from these meetings have been incorporated into the study plan. Efforts are made to keep people in the basin informed throughout the study using the Internet, news releases, and other means of contact. Public and technical inputs were invited throughout the study period. One common criticism among the communities in Canada affected by the Red River flooding was the lack of their involvement in decisions made on flood control and flood protection measures implemented by the government (Simonovic & Carson, 2003).

In investigating what can be done about flooding in the Red River basin, the Task Force examined the issue of storage—through reservoirs, wetlands, small impoundments or micro-storage, and drainage management. The Task Force considered how much storage would be required to reduce the impact of a major flood on the scale of 1997 and whether there was sufficient potential in the basin to meet that storage requirement. The conclusions (International Joint Commission, 2000) are:

- *Conclusion 2*. It would be difficult if not impossible to develop enough economically and environmentally acceptable large reservoir storage to reduce substantially the flood peaks for major floods.
- *Conclusion 4*. Wetland storage may be a valued component of the prairie ecosystem but it plays an insignificant hydrologic role in reducing peaks of large floods on the main stem of the Red River.

Since, as the Task Force concluded, storage options provide only modest reductions in peak flows for major floods, a mix of structural and non-structural options were examined. The cities of Grand Forks and East Grand Forks are in the process of building dikes and undertaking urban renewal projects in response to the flooding suffered by those cities. Other communities are also taking action, and the final report examined some of those undertakings. Winnipeg, the largest urban area within the basin, remains at risk. The city survived the flood relatively unharmed, but Winnipeg cannot afford complacency. The Task Force made a number of recommendations to address the city's vulnerabilities and better prepare it for large floods in the future. The Task Force concluded that:

- *Conclusion 6*. Under flow conditions similar to those experienced in 1997, the risk of a failure of Winnipeg's flood protection infrastructure is high.

The city needs a higher level of flood protection. The Task Force recommends that:

- *Recommendation 4*. The design flood used as the standard for flood protection works for Winnipeg should, at a minimum, be the flood of record, the 1826 flood, or higher if economically justified.

A number of immediate actions were recommended including modifying the east embankment of the Floodway, raising the west dike, and raising the primary diking system where economically feasible to the elevation specified in existing legislation. However, to achieve the level of protection sufficient to defend against the 1826 or larger floods, major structural measures on a scale equal to the original floodway project are needed to protect the city. After the detailed feasibility studies and a federal–provincial–city agreement, the Floodway expansion project is under construction (the largest infrastructure investment in Canada at the moment—2006).

Structural protection measures are only part of the response to living with major floods. The Task Force looked at a wide range of floodplain management issues to see how governments and residents might establish regulatory and other initiatives to mitigate the effects of major floods and to make communities more resilient to the consequences of those floods. It made a number of recommendations on defining the floodplain, adopting and developing building codes appropriate to the conditions in the Red River basin, education, and enforcement. The Task Force supported the acquisition of properties in the greatest danger of being flooded and recommended policy changes in Canada and the United States to allow an acquisition policy to be coordinated with other flood protection measures.

Federal Emergency Management Agency (FEMA) in US and Emergency Preparedness Canada were charged to develop an integrated approach to mitigation initiatives based on a comprehensive mitigation strategy for the basin. In the United States, the strategy was recommended to be integrated within the National Mitigation Strategy. The Task Force found the lack of flood mitigation strategy in Canada an obstacle in the way of developing a more flood resilient basin and recommended that:

- *Recommendation 23*. The Canadian federal government should establish a national flood mitigation strategy, or a broader disaster mitigation strategy, and support it with comprehensive mitigation programs.

Flood insurance is an integral part of the US approach to flood preparedness yet the program attracts far too few people at risk. The Task Force recommended that:

- *Recommendation 24*. In the US portion of the Red River basin, FEMA should expand current efforts to market the sale and retention of flood insurance both within and outside the 100-year floodplain. Innovative marketing should be considered to attract and retain policy holders, including increasing the waiting period from 30 days to 60 days before flood insurance comes into effect.

In an effort to gain a better understanding of the flooding issues and in recognition of weaknesses in technological infrastructure within the basin, the Task Force devoted much of its energy and resources to data issues and computer modeling. On reviewing current data availability, the Task Force concluded that further improvement and maintenance of the Red River floodplain management database is required. Federal, state and provincial governments and local authorities must maintain a high level of involvement in further database development and in improving data accessibility.

The database, computer models, and decision-support system were seen to remain as a legacy to aid flood fighters and planners with the latest computer models and information base for effective planning and real-time decision-making during flood crises. Recommendations of the Task Force included:

- *Recommendation 35*. Hydrometric and meteorological data networks necessary for flood forecasting should be improved and maintained in a state of readiness to forecast future floods.
- *Recommendation 41*. Development of the digital elevation model for the Red River Basin should be completed by collaborative initiatives of the relevant agencies.
- *Recommendation 42*. Relevant federal, provincial, state agencies and transboundary agencies should meet to determine the interest in continuing the work of the Red River Basin Disaster Information Network (RRBDIN) and draw up a funding and action plan to ensure its continuation.

The Red River Basin Decision Information Network (RRBDIN) provides now information about water management within the basin, and links to other relevant resources. While RRBDIN concentrates more on the information and activities on the US side, the Government of Manitoba has been involved in collecting and disseminating flood information from the Canadian side. Information from RRBDIN includes databases, references, technical tools, communication tools, and GIS data as well as the most updated information on weather and flood forecasting.

The Task Force found difficulty in securing public access from Canadian agencies to data and other flood-management related information. Policies that restrict access to flood related data frustrate the development of a basin-wide virtual database and can endanger effective response to flood fighting and management efforts. The Task Force recommended making Canadian data available at no cost and with no restrictions for floodplain management, emergency response, and regional or basin-wide modeling activities. The website of the Government of Manitoba now provides up-to-date daily flood conditions, in the form of maps and reports, along with miscellaneous information on floodplain management. A prototype version of the real time flood decision support for the Red River basin is operational.

The Task Force supported the development of ‘‘unsteady flow’’ hydraulic models that can simulate floodwater flows. It also reviewed the other modeling activity in the basin, particularly US hydrologic models. These models are seen to be in the forefront of future floodplain planning and real-time flood fighting. The Task Force recommended that the US National Weather Service implement its Advanced Hydrologic Prediction System in the Red River basin as an early priority. It also recommended a basin-wide coupled atmospheric–hydrologic model in the Red River basin as a long-term priority for government and academic research. Concerning its own hydraulic models, the Task Force recommended a secondary roads survey and that the data generated be incorporated into the models. As for maintenance of the Task Force-developed hydraulic models, the Task Force recommended that:

- *Recommendation 49*. The US Army Corps of Engineers and the Manitoba Department of Conservation, operators of the UNET and MIKE 11 models respectively, should maintain the existing models and continue to seek improvements through collaboration with other agencies.

The Task Force provided support for research to develop a multi-criteria decision-making methodology for participatory process governing the floodplain management in the Red River Basin. This methodology should be able to: (1) evaluate potential floodplain management alternatives based on the multiple criteria under uncertainty and input from multiple stakeholders, (2) accommodate the high diversity and uncertainty inherent in human preferences, and (3) handle a large amount of data collected from stakeholders in the Red River Basin.

This paper presents, in Section 2, a new methodology and its application to the Red River Basin floodplain management in Section 3. A set of conclusions is provided at the end.

2. Methodology

The floodplain management process in Canada, as elaborated for the Red River basin by Simonovic (1999), has three major stages: (a) planning, (b) flood emergency management, and (c) post-flood recovery. Appropriate decision-making in each of these stages is very important to establish an efficient floodplain management process. During the planning stage, different alternative measures (both structural and non-structural) are analyzed and compared for possible implementation in order to minimize future flood damage. Flood emergency management includes regular evaluation of the current flood situation and daily operation of flood control works. The evaluation process includes identification of potential events that could affect the current flood situation (such as dike breaches, wind set-up, heavy rainfall, etc.) and identification of corresponding solution measures for flood fighting (including building temporary structures or upgrading existing ones). Also, from the evaluation of current situation, decisions are made regarding evacuation and re-population of flood-affected areas. Post-flood recovery involves numerous decisions regarding return to normal life. Main issues during this stage include assessment and rehabilitation of flood damage, and provision of flood assistance to flood victims. In all these three stages, the decision-making process takes place in a multi-disciplinary and multi-participatory environment.

Floodplain management decision-making problems at each of the three stages are complex due to their multi-criteria nature. For a given goal, many alternative solutions may exist that provide different level of satisfaction for different issues, such as environmental, social, institutional and political. These concerns naturally lead to the use of multi-criteria decision-making techniques, in which, trade-off is performed among the single objectives to find out the most desirable solution. Multiple criteria decision-making becomes more complicated with the increase in number of individuals/groups involved in the decision-making process. In reality, the decision-making process often involves multiple stakeholders/decision makers. Moving to a multiple stakeholders' participation introduces a great deal of complexity into the analysis. The decision problem is no longer limited to the selection of the most preferred alternative among the non-dominated solutions according to a single set of preferences. The analysis must also be extended to account for the conflicts among different stakeholders with different objectives. Therefore, it is a real challenge to have a group decision outcome that can satisfy all who are involved in the decision-making process (Arrow, 1963).

In general, the process of decision-making basically involves deriving the best option from a feasible set of alternatives. Most of the existing approaches in multiple criteria decision-making with a single stakeholder/decision maker consist of two phases (Zimmerman, 2001): (1) the aggregation of the judgments with respect to all criteria and per decision alternatives and (2) the ranking of the decision alternatives according to the aggregated judgment. In the case of multiple stakeholders, an additional aggregation is necessary with respect to the judgments of all the stakeholders. Group decision-making under multiple criteria involves a diverse and interconnected fields like preference analysis, utility theory, social choice theory, voting, game theory, expert evaluation analysis, aggregation, economic equilibrium theory and so on (Hwang & Lin, 1987).

Table 1
Conceptual decision matrix for a discrete multi-criteria multi participant decision problem

	O_1	...	O_p
A_1	a_{11}	...	a_{1p}
...	...	...	...
A_m	a_{m1}	...	a_{mp}
DM_1	w_{11}	...	w_{1p}
...	...	...	...
DM_n	w_{n1}	...	w_{np}

Consider a multi-criteria multi participant decision-making problem where m alternatives are to be evaluated by n decision makers, who are using p objectives. The general conceptual decision matrix for the discrete multi-criteria multi participant problem is shown in Table 1.

In Table 1, A denotes the alternative, O the criterion and DM is the decision maker/stakeholder. The preference of the decision maker k ($k = 1, \ldots, n$) for the objective j ($j = 1, \ldots, p$) is expressed by w_{jk}, and a_{ij} is the performance evaluation of the alternative i ($i = 1, \ldots, m$) for each objective j.

The classical outcome of the decision matrix is the ranking of the alternatives. To obtain that, a number of steps are necessary like establishing the preference structure, the weights and also the performance evaluations. All these can be termed as the inputs for the decision matrix. These inputs come from the stakeholder/decision maker. The decision matrix shows that the inputs can be for the preference of criteria as well as for the performance evaluations. The decision maker might also have a preference structure for the alternatives. In case of multi participant decision-making problem, these inputs are to be collected from all the stakeholders.

Following is a general mathematical formulation of this multi criterion, multi participant problem (Hwang & Lin, 1987). A payoff matrix can be obtained for the problem where m alternatives are to be evaluated by n stakeholders/decision makers, who are using p criteria:

$$A^k = [a_{ij}]^k = \begin{bmatrix} a_{11} & .. & .. & a_{1p} \\ a_{21} & .. & .. & a_{2p} \\ .. & .. & .. & .. \\ a_{m1} & .. & .. & a_{mp} \end{bmatrix} \quad (k = 1, \ldots, n) \tag{1}$$

Here $A_i^k = [a_{i1}, \ldots, a_{ip}]^k$ means that alternatives i are being evaluated by criteria from 1 to p by decision maker k. The symbol $A_j^k = [a_{1j}, \ldots, a_{mj}]^k$ means that the objective j is being used by decision maker k to evaluate all alternatives from 1 to m.

The solution to this problem is to have each alternative evaluated by all the decision makers using all criteria. The process can be summarized as the following mapping function:

$$\Psi : \{A^k | k = 1, \ldots, n\} \rightarrow \{G\} \quad (2)$$

where G is a collective weighted agreement matrix. It is crucial that this mapping function represents all criteria that the decision makers use in judging all the alternatives.

Floodplain management decision-making is always associated with some degree of uncertainty. This uncertainty could be categorized into two basic types: uncertainty caused by inherent hydrologic variability and uncertainty due to a lack of knowledge (Simonovic, 2000). Uncertainty of the first type is associated with the spatial and temporal changes of hydrologic variables such as flow, precipitation, and water quality. The second type of uncertainty occurs when the particular value of interest cannot be assessed exactly because of the limitation in the available knowledge. The second type of decision uncertainty is more profound in the area of public decision-making such as in the case of floodplain management.

Capturing views of individual stakeholders contributes to increase in decision uncertainty. The major challenge while collecting the views of stakeholders is to find out the technique that will effectively capture decision uncertainties, and also will be usable in a multi-criteria decision-making tool.

2.1. Participation of multiple stakeholders

An aggregation procedure is one of the ways to include information from the participating decision makers into the decision matrix. The available methods do not seem to be appropriate for floodplain management for two reasons. The first is that all available methods collect the information from the multiple participants using relatively complicated procedures. Where the participating decision makers, as in case of floodplain management, are from both technical and non-technical backgrounds, the application of the complicated procedures is not feasible. The second reason is that when the responses are collected from a large number of participants, there may be a number of common responses. This overlap will not be reflected in the results if traditional (direct aggregation) methods are applied.

The methodology of the present study (Akter & Simonovic, 2005) includes representation of inputs from a large number of participants and the analysis of inputs to make them usable for the application to various multi-criteria decision-making methods. Fuzzy set theory and fuzzy logic are used to represent the uncertainties in stakeholders' opinions. Three possible types of fuzzy input have been considered to capture the subjectivity of the responses from stakeholders. When a stakeholder is asked to evaluate an alternative against a particular criterion, the answer may take one of the following forms: (a) a numeric scale response, (b) a linguistic answer (for example: poor, fair, good, very good, etc.), or (c) an argument (for example: 'if some other condition is satisfied then it is good'). For the first type, the input is quite straightforward. For type (b) answer, it will be necessary to develop the membership functions for the linguistic terms. Type (c) input can be described by using fuzzy inference system, which includes membership functions, fuzzy logic operators and if-then rule. For this, the membership functions for the input arguments need to be developed first. Then fuzzy operator and fuzzy logic are applied to obtain the output. It should be noted that the interpretation of type (b) and type (c) input values are highly dependent on the shape of the membership functions and the degree of severity chosen by the expert for a particular application.

After receiving the inputs from all stakeholders, the next step is to aggregate those inputs to find a representative value. It is obvious that for all input types considered above, the responses are sure to be influenced by a number of repetitions. This means many respondents can provide the same response. This implies that the general methodologies of fuzzy aggregation cannot be applied for deriving the resultant input from a large number of decision makers. Fuzzy Expected Value (FEV) method can be used instead to get the resulting opinion of the stakeholders.

Following is the definition of the Fuzzy Expected Value: Let χ_A be a B-measurable function such that $\chi_A \in [0, 1]$. The FEV of χ_A over the set A, with respect to the fuzzy measure μ, is defined as:

$$\mathrm{FEV}(\chi_A) = \sup_{T \in [0,1]} \{\min[T, \mu(\xi_T)]\} \quad (4)$$

$$\text{where } \xi_T = \{x | \chi_A(x) \geq T\} \quad (5)$$

$$\text{and } \mu\{x | \chi_A(x) \geq T\} = f_A(T) \text{ is a function of the threshold} T \quad (6)$$

Fig. 1 provides a geometric interpretation of the FEV. Performing the minimum operator, the two curves create the boundaries for the remaining triangular curve. The supremum operator returns the highest value of $f_A(T)$ which graphically represents the highest point of the triangular curve. This corresponds to the intersection of the two curves where $T = H$.

FEV can be computed for all three types of inputs mentioned earlier in this section. For type (a) input, the resultant FEV should be a numeric value between 0 and 1. For both type (b) and type (c) inputs, the resultant FEVs are membership

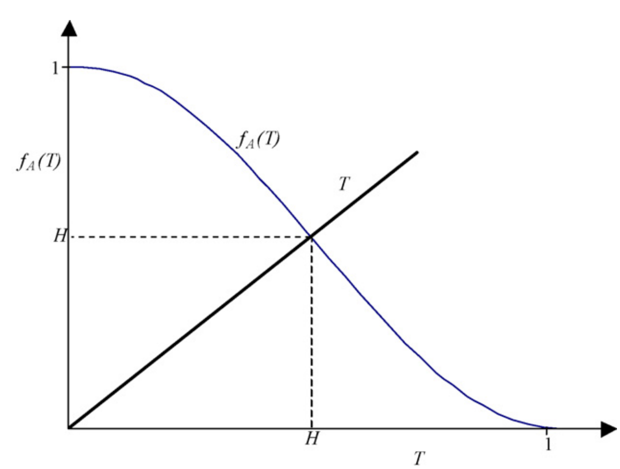

Fig. 1. A geometric interpretation of the FEV.

functions. The crisp numeric equivalents of these membership functions can be obtained by applying defuzzification method and can then be compared with type (a) answers.

The centroid of area defuzzification method has been used that returns a value obtained by averaging the moment area of a given fuzzy set. Mathematically, the centroid, $\bar{x}$, of a fuzzy set, A, is defined as:

$$\bar{x} = \frac{\int_0^1 x\mu_A(x)\,\mathrm{d}x}{\int_0^1 \mu_A(x)\,\mathrm{d}x} \tag{7}$$

where $\mu_A(x)$ is the membership function of the fuzzy set A.

The resultant FEVs are now the aggregated evaluation of the alternatives from all the stakeholders. They can now be used as the input value in the decision matrix (Table 1) for the multi-criteria analysis.

2.2. Participatory multi-criteria decision-making under uncertainty

In this paper, an innovative modification has been made to the Compromise Programming multi-criteria decision-making technique to accommodate participatory flood decision-making under uncertainty. Bender and Simonovic (2000) fuzzified Compromise Programming entirely and thus formulated Fuzzy Compromise Programming (FCP). The driving force for the transformation from a classical to a fuzzy environment is that there is a need for accurate representation of subjective data in the flood decision-making. It is the theory of fuzzy sets that can represent the subjective data well. Thus, instead of using crisp numbers in the Compromise Programming distance metric equation, fuzzy numbers are used; instead of using classical arithmetic, fuzzy arithmetic is applied; instead of simply sorting distance metrics, fuzzy set ranking methods must be applied to sort the fuzzy distance metrics. In other words, the fuzzy transformation complicates the interpretation of the results but, on the other hand, models the decision-making process more realistically.

Mathematically, Compromise Programming distance metric in its discrete form can be presented as:

$$L_j = \left[\sum_{z=1}^{t}\left\{w_z^p\left(\frac{f_z^* - f_z}{f_z^* - f_z^-}\right)^p\right\}\right]^{1/p} \tag{8}$$

where $z = 1, 2, 3, \ldots, t$ and represents t criteria, $j = 1, 2, 3, \ldots, n$ and represents n alternatives, L_j is the distance metric of alternative j, w_z corresponds to a weight of a particular criteria, p is a parameter ($p = 1, 2, \infty$), f_z^* and f_z^- are the best and the worst value for criteria z, respectively (also referred to as positive and negative ideals), and f_z is the actual value of criterion z.

The parameter p is used to represent the importance of the maximal deviation from the ideal point. Varying the parameter p from 1 to infinity, allows one to move from minimizing the sum of individual regrets (i.e. having a perfect compensation among the criteria) to minimizing the maximum regret (i.e. having no compensation among the criteria) in the decision-making process. The choice of a particular value of this compensation parameter p depends on the type of problem and desired solution.

The weight parameter, w_z, characterizes decision makers' preference concerning the relative importance of criteria. Simply stated, the parameter places emphasis on the criteria the decision maker deems important. The parameter is needed because different participants in the decision-making process have different viewpoints concerning the importance of a criterion.

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In Fuzzy Compromise Programming, obtaining the smallest distance metric values is not easy, because the distance metrics are also fuzzy. To pick out a smallest fuzzy distance metric, from a group of distance metrics, fuzzy set ranking methods have to be used. A study by Prodanovic and Simonovic (2002) compared fuzzy set ranking methods for use in Fuzzy Compromise Programming, and recommended using the method of Chang and Lee (1994). This recommendation was founded on the fact that Chang and Lee's (1994) method gave most control in the ranking process—with degree of membership weighting and the weighting of the subjective type. The Overall Existence Ranking Index (OERI) suggested by Chang and Lee (1994) has the following mathematical form:

$$\mathrm{OERI}(j) = \int_0^1 \omega(\alpha)\left[\chi_1\mu_{j\mathrm{L}}^{-1}(\alpha) + \chi_2\mu_{j\mathrm{R}}^{-1}(\alpha)\right]\mathrm{d}\alpha \tag{9}$$

where the subscript j stands for alternative j, while α represents the degree of membership; χ_1 and χ_2 are the subjective type weighting indicating neutral, optimistic or pessimistic preferences of the decision maker, with the restriction that $\chi_1 + \chi_2 = 1$; parameter $\omega(\alpha)$ is used to specify weights which are to be given to certain degrees of distance metric membership (if any); $\mu_{j\mathrm{L}}^{-1}(\alpha)$ represents an inverse of the left part and $\mu_{j\mathrm{R}}^{-1}(\alpha)$ the inverse of the right part of the distance metric membership function.

For χ_1 values greater than 0.5, the left side of the membership function is weighted more than the right side, which in turn makes the decision maker more optimistic. Of course, if the right side is weighted more, the decision maker is more of a pessimist (this is because he/she prefers larger distance metric values, which means the farther solution from the ideal solution). In summary, the risk preferences are: if

$\chi_1 < 0.5$, the user is a pessimist (risk averse); if $\chi_1 = 0.5$, the user is neutral; and if $\chi_1 > 0.5$, the user is an optimist (risk taker). Simply stated, Chang and Lee's (1994) Overall Existence Ranking Index is a sum of the weighted areas between the distance metric membership axis and the left and right inverses of a fuzzy number.

3. Red River Basin floodplain management

The proposed methodology is applied to floodplain management in the Red River Basin (IJC, 2000; Simonovic, 1999; Simonovic & Carson, 2003). One of the floodplain management problems at the planning stage in the Red River Basin is the complex, large-scale problem of ranking potential floodplain management alternatives. During the evaluation of alternatives, it is necessary to consider multiple criteria that may be quantitative and qualitative. The floodplain management process in the basin also involves numerous stakeholders. They include different levels of government, different agencies, private organizations, interest groups and general public. They all have different and specific needs and responsibilities during all stages of floodplain management—planning, emergency management and flood recovery.

Currently, the Government of Manitoba, Canada is responsible for decision-making about floodplain management measures. The decision-making process involves consulting different organizations for their technical input. Concerns of the general public about the alternatives are gathered through public hearings and workshops. Economic analysis plays an important role in formulating plans for reducing flood damages and making operational decisions during the emergency. One of the main limitations of the existing floodplain management methodology is high emphasis on the economic criterion. Very minor attention is given to environmental and social impacts of floods.

There has been increasing concern of general public about the decisions to be taken on the selection of flood control measures. During the 1997 flood, it was indicated that certain stakeholders in the basin, particularly the floodplain residents, did not have adequate involvement in floodplain management decision-making. Dissatisfaction has been observed among the stakeholders about evacuation decisions during the emergency management and about compensation decisions during the post-flood recovery (IJC, 2000).

The methodology presented in the previous section involves: (i) data collection from all stakeholders, (ii) data aggregation, (iii) derivation of stakeholders priorities, (iv) development of the floodplain management pay-off (decision) matrix, and (v) selection of an alternative that provides the best available trade off. Through the application of the proposed methodology the empowerment of stakeholders is provided for improved floodplain decision-making. Since the methodology is complex its transparent implementation is provided in the following way. The first part of the methodology – data collection – has been developed to support collection of information from all stakeholders in the way that fits the best their way of expressing themselves. Data aggregation step together with derivation of preferences step are numerical in nature and therefore are executed without direct communication with the stakeholders. However, results of these two steps are presented, in step four, to the stakeholders in the concise and clear form of the floodplain management pay-off (decision) matrix. This is the step where stakeholders can actively process the information generated using sophisticated mathematics of steps two and three. When approved by the stakeholders, the floodplain management pay-off matrix is processed in order to arrive at the best trade-off decision that involves value of all stakeholders taking part in the process.

The methodology presented in the previous section has been used to collect information from the stakeholders across the Canadian portion of the Red River Basin. In order to evaluate the utility of the methodology, a generic experiment was considered for the study to evaluate three alternative options for improved floodplain management. A floodplain management pay-off (decision) matrix with relevant criteria and theoretical alternatives was developed for this case study as shown in Fig. 2.

Three generic options considered are: (a) structural alternatives, (b) non-structural alternatives, and (c) a combina-

	Economic Criteria			Environmental Criteria			Social Criteria	
	Cost	Damage	Benefit	Chemical Contamination	Alien Species	Environment	Community Involvement	Personal Loss
Structural Alternative	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{16}	e_{17}	e_{18}
Non-Structural Alternative	e_{21}	e_{22}	e_{23}	e_{24}	e_{25}	e_{26}	e_{27}	e_{28}
Combination Alternative	e_{31}	e_{32}	e_{33}	e_{34}	e_{35}	e_{36}	e_{37}	e_{38}
Weight Coefficient	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8

*Stakeholder preference, e_{mn}

Fig. 2. Floodplain management pay-off (decision) matrix.

tion of both. The selection of criteria against which the alternatives are ranked is one of the most difficult but important tasks of any multi-criteria decision analysis. For the floodplain management decision-making in the Red River Basin, the criteria selection is mainly based on prior studies of the Red River flooding (IJC, 2000; Morris-Oswald, Simonovic, & Sinclair, 1998). Economic objectives (cost, damage, benefit, etc.) are in general the most important ones and also are straightforward to quantify. Environmental objectives (chemical contamination; inter-basin transfer of alien invasive species; and protection and enhancement of floodplain environment) are highly important too. Generally, most floodplain management decision-making processes exclude or ignore the social objectives. This is mainly because of the difficulties inherent in selecting and quantifying these objectives. Different studies of the Red River flooding and numerous interviews with its stakeholders reflect that including social impacts is of prime importance for a successful implementation of any floodplain management policy in the Red River Basin. The following two social objectives have been considered in our case study: (a) level of community involvement and (b) amount of personal losses (include financial, health and psychological losses).

A detailed survey has been conducted in the Basin to collect the information on the two selected social criteria (Salonga, 2004). Therefore, the remaining of this paper focuses on the application of the developed methodology using a generic set of three alternatives and the real data on two social criteria. The survey questionnaire was prepared: (a) to capture the possible views of the stakeholders for the two selected criteria (eight questions for criterion 1 and five questions for criterion 2) and (b) to allow stakeholders to express their views in an easy way. Thirty-five respondents were interviewed and they were asked to answer each question in three forms: (a) using a numeric scale with the range of 0–1, (b) using linguistic answers (very low, low, medium, high, very high), and (c) using conditional answers:

- [if flooding is moderate then (very low, low, medium, high, very high)] and
- [if flooding is severe then (very low, low, medium, high, very high)].

All three types of inputs obtained from all the stakeholders were processed using the Fuzzy Expected Value method as explained in Section 2. For the conditional response, the response from each person was first processed to get the crisp value, and then all the responses were further processed to obtain the FEV using the method for scale responses.

Table 2 summarizes the results of all three types of inputs (scale, linguistic and conditional types which are termed as A, B and C, respectively, in the table) as the evaluation of three alternatives (structural, non-structural, combination) against two criteria (community development, personal loss). Obtained results show good correlation between the numeric scale type and linguistic type of inputs with an average difference of only 0.029. The conditional type results show consistently a slightly lower value. This can be attributed to the fact that, to obtain the resultant linguistic input from the conditional statements, it is required to select a level of severity for the flooding considered. In this case, we took 1997 flooding of the Red River to be of 0.7 degree of severity on the scale from 0 to 1. This value is subject to change according to the expert opinion, and if a higher value is chosen the results would be closer to the other type values.

All the three methods used in this study can be claimed to be equally accurate in representing the stakeholders' view. The degree of superiority of one above others has not been measured in this study.

Table 2
Resultant FEVs

Question number	Alternative								
	Structural			Non-structural			Combination		
	A	B	C	A	B	C	A	B	C
Community involvement									
1	0.600	0.650	0.544	0.647	0.650	0.544	0.600	0.625	0.544
2	0.529	0.517	0.500	0.500	0.517	0.491	0.500	0.570	0.544
3	0.618	0.700	0.529	0.559	0.625	0.529	0.600	0.625	0.544
4	0.600	0.650	0.544	0.657	0.650	0.559	0.686	0.650	0.544
5	0.700	0.700	0.559	0.629	0.650	0.544	0.700	0.650	0.544
6a	0.800	0.825	0.677	0.704	0.770	0.588	0.800	0.825	0.647
6b	0.771	0.770	0.588	0.714	0.717	0.574	0.743	0.770	0.574
6c	0.700	0.700	0.574	0.629	0.650	0.574	0.686	0.700	0.574
7	0.800	0.825	0.735	0.829	0.850	0.718	0.857	0.825	0.718
8	0.700	0.717	0.574	0.700	0.650	0.574	0.700	0.700	0.574
Personal loss									
1	0.800	0.770	0.718	0.700	0.700	0.574	0.700	0.717	0.671
2	0.588	0.570	0.544	0.600	0.650	0.544	0.600	0.625	0.574
3a	0.500	0.570	0.574	0.559	0.625	0.574	0.559	0.570	0.574
3b	0.700	0.717	0.625	0.700	0.717	0.588	0.706	0.717	0.588
4	0.771	0.770	0.574	0.700	0.650	0.574	0.700	0.717	0.544
5	0.500	0.570	0.529	0.700	0.570	0.544	0.571	0.570	0.544

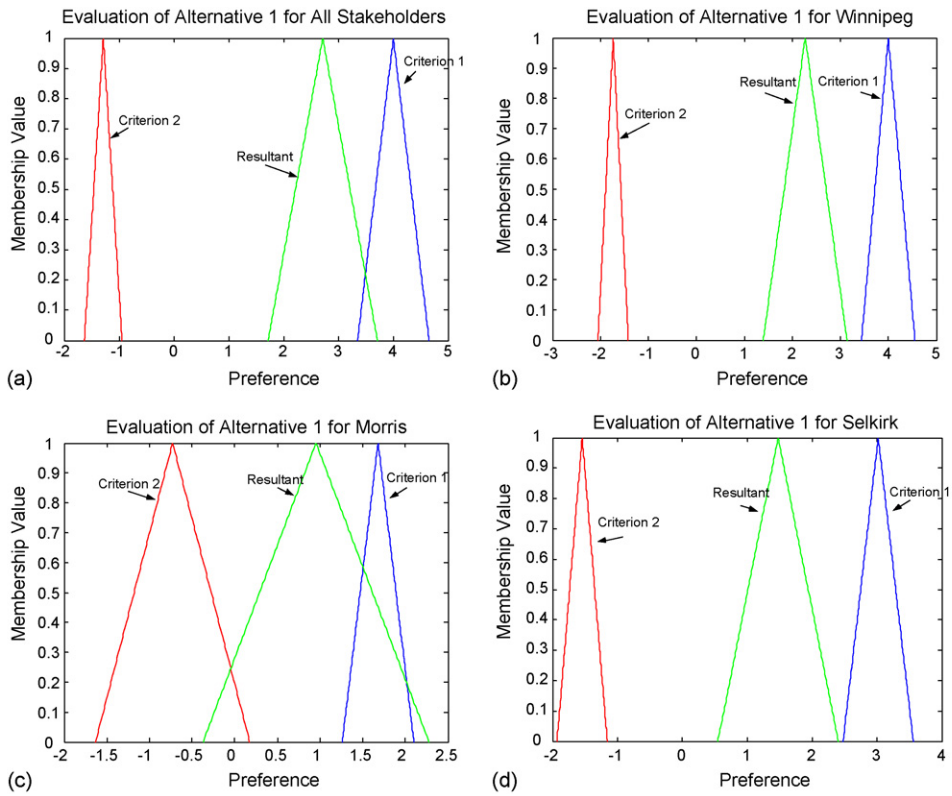

Fig. 3. The distance metric fuzzy membership functions.

FEVs obtained in Table 2 are used further to rank the three generic alternatives. All questions are considered to carry the same weight. A set of ranking experiments has been conducted to evaluate the impact of different stakeholder groups on the final rank of alternatives: (a) experiment 1—all stakeholders interviewed, (b) experiment 2—stakeholders from the city of Winnipeg, (c) experiment 3—stakeholders from the Morris area (south of Winnipeg), and (d) experiment 4—stakeholders from the Selkirk area (north from Winnipeg).

Fig. 3 shows for illustrative purposes, the criterion 1, the criterion 2 and the resultant distance metric membership functions obtained in evaluation of alternative 1 (structural floodplain management option) for (a) all participants, (b) participants from the City of Winnipeg, (c) participants from the Morris area and (d) participants from the Selkirk area.

The final results of four ranking experiments with three generic alternatives and two social criteria are shown in Table 3 (defuzzified distance metric value and the rank in brackets). It is obvious that the final rank varies with the experiment, therefore confirming that preferences of different stakeholders are being captured by the developed methodology.

Table 3
Final rank of floodplain management alternatives

Participants	Alternative 1	Alternative 2	Alternative 3
All stakeholders	13.224 (1)	13.717 (3)	13.280 (2)
Morris	15.435 (2)	16.086 (3)	13.636 (1)
Selkirk	14.635 (3)	14.425 (1)	14.585 (2)
Winnipeg	13.746 (1)	15.259 (3)	13.923 (2)

4. Conclusions

Though flood control decisions (i.e. disaster mitigation, preparedness and management) may be designed and made without the stakeholders' participation, they cannot be effectively implemented without it (Affeltranger, 2001). So, floodplain management decision-making can be defined as a multi-criteria, multi participant problem where alternatives are evaluated against a number of criteria considering the concerns of all stakeholders. As most of the decision-making processes take place in situations where the goals, the constraints and the consequences of the possible actions are not known precisely, it is necessary to include these types of uncertainty into the decision-making methodology. Fuzzy set and fuzzy logic techniques have been used successfully to represent the imprecise and vague information in many fields, and so have been considered as an effective way to represent uncertainties in this study. This work proposes a new methodology that provides alternative ways to extract and aggregate the inputs from a large number of stakeholders for floodplain management decision-making. Fuzzy Expected Value (FEV) has been used as a method to aggregate those inputs and generate the elements of the multi-criteria decision matrix for further analysis (Akter & Simonovic, 2005). Three possible types of responses for floodplain management have been considered which are numeric input, linguistic input and conditional input. The Fuzzy Compromise Programming technique (Bender & Simonovic, 2000) is combined with the fuzzy membership ranking (Prodanovic & Simonovic, 2002) to analyze the alternative floodplain management options.

The methodology developed in this paper has a highly mathematical background that may reduce its acceptability by many stakeholders. However, the implementation of the methodology is suggested in such a way to provide its acceptability without compromising the mathematical rigor. Data is collected from the stakeholders using ways that assist them in expressing their values. Mathematically processed information is summarized for the stakeholders before the final decision-making step in a clear and concise way. The final decision is based on the values collected from all stakeholders that provides for its acceptability and high level of transparency. The methodology can be implemented step-by-step. Any concern raised about transparency can be addressed by repeating the step during which the concern is raised.

The analyses of floodplain management options in the Red River Basin has successfully tested the applicability of the methodology for a real floodplain management decision-making problem. The stakeholders can now express their concerns regarding flood hazard in an informal way, and that can be incorporated into the multi-criteria decision-making model. The application of methodology helps in solving the problem of incorporating a large number of stakeholders in floodplain decision-making process.

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