Water Resour Manage (2009) 23:1549–1561
DOI 10.1007/s11269-008-9340-y

A Compromise Solution in Water Resources Planning

Serafim Opricovic

Received: 2 February 2007 / Accepted: 1 September 2008 /
Published online: 18 September 2008

Abstract The paper emphasizes compromise based on cooperativeness as a solution of a decision problem in water resources planning. A decision making process committed to consensus utilizing compromise solution as a consensus proposal is presented. The presented methodology is utilized to study the development of a reservoir system for the storage of surface flows of the Mlava River and its tributaries for regional water supply. The method VIKOR is applied to determine compromise solution of a problem with noncommensurable and conflicting criteria including economic, environmental, social, and cultural features. The obtained compromise provides a maximum group utility of the "majority" and a minimum individual regret of the "opponent".

Keywords Reservoir system design · Regional water supply · Multicriteria decision making · Compromise

1 Introduction

Land and waters in the world are under increasing pressure from the continuous growth in demand for many different purposes, and the allocation of water in the river basin is a complex management problem, with conditions that may foster conflicts. Conflict over the management of a shared water resource arises mostly because of differing objectives among different interest groups. Many authors have been considering the conflicts resolution in water resources planning (Just and Netanyahu 1998; Babel et al. 2005). "Water Wars" have been discussed "…the states regularly accuse another state of stealing their water" (McNulty 1986). The engineers and other experts have been involved in many attempts to develop a

S. Opricovic (✉)
Faculty of Civil Engineering, University of Belgrade,
Bulevar Kralja Aleksandra 73, 11000, Belgrade, Serbia
e-mail: seropric@yahoo.com

workable decision making process. Many papers seek to determine how engineers could have been more effective in their attempts to help decision makers achieve an acceptable compromise (Simonovic 1996; Cai et al. 2004; Srdjevic et al. 2004; Zarghaami 2006). Beside many disadvantages of a conflict situation, a conflict can be good if based on issues, enhances constructive problem solving and creativity, and challenging complacency, status quo and stagnation.

There exist normative methods oriented towards aiding the conflict resolution by identifying and evaluating alternative strategies and solutions. This approach requires that various desirable goals be specified, and the normative method explores ways of reaching these goals through alternative paths and decision points. A normative approach in conflict resolution indicate ways that parties should deal with conflict, not how they actually do or will deal with it. Bell et al. (1985) proposed the prescriptive approach to bring the normative and explicative together. According to this approach, prescriptive decision makers consult rational, normative models for optimizing the interests of parties in a conflict; at the same time, they are willing to bend decisions around imperfect information or emotional factors. Hence normative methods can provide parties in a conflict with prescriptive frameworks to guide behaviour so that courses of action, consequences, and risks and benefits become less uncertain. Among these methods, those that seem to predominate include multicriteria decision making (Bogardi and Nachtnebel 1994; Raju et al. 2001; Hyde et al. 2004). Hajkowicz and Collins (2007) review multiple criteria analysis for water resource planning and management, identifying 113 studies published since 1973.

Conflict resolution is considered here as a multicriteria decision making (MCDM) problem. The criteria usually conflict with each other and there may be no solution optimizing all criteria simultaneously. Thus, the concept of Pareto optimality was introduced for a vector optimization problem (Zadeh 1963). Pareto optimal (non-inferior) solutions have the characteristic that, if one criterion is to be improved, at least one other criterion has to be made worse. In engineering and management practice there is a need to select a final solution to be implemented. An approach to determine a final solution as a compromise was introduced by Yu (1973). Based on this approach, the method VIKOR has been developed to solve a discrete decision problem with noncommensurable and conflicting criteria (Opricovic and Tzeng 2004, 2007).

Decision making is a process which starts with an idea and ends with the actual implementation of the decision. An appropriate MCDM procedure has the following steps:

(a) Defining the decision problem
(b) Establishing objectives and evaluation criteria
(c) Developing alternatives for attaining the goals (generating alternatives)
(d) Evaluating alternatives in terms of criteria
(e) Preparing consensus proposal applying a normative compromise method
(f) Making decision accepting one alternative as “optimal” (preferred)
(g) If the final solution is not approved, gathering new information and going to the next iteration of this decision making procedure.

This paper aims to formal consensus solution through normative compromise. It is organized as follows. In Section 2, the decision problem is identified. Four basic elements involved in decision making are reviewed in Section 3. Cooperation and compromising significance in water resources development is discussed in Section 4, addressing the issue of multicriteria analysis and compromise solutions. In Section 5, the VIKOR method is applied to determine compromise solution for the water resources system in Serbia, introducing VIKOR as a normative method for multicriteria decision making by compromising. Section 6 closes the paper with discussion and conclusion. The Appendix shows the algorithmic steps of the VIKOR method.

2 Recognition of Decision Problem

The main goal in this example is the development of reservoir system for the storage of surface flows of the Mlava River and its tributaries. Ideas for the development of this reservoir system were proposed more than 60 years ago. The previous studies pointed out the possibilities of using this water resource for water supply of several cities in the region. The topographic surveys confirmed that the required reservoir capacity is available, but a hydrological solution conflicts with infrastructure systems and with environmental, social, and cultural features. In 1954 reservoir Gradac with normal level of 280 m a.s.l. in the gorge Ribarska was considered (see alternative A4 in Section 3). In 1960 reservoir Vukan (225) was considered. Both solutions were in conflict with natural and social environment. The dam site Vitman was considered in 1984 avoiding the removal of the monastery Gornjak.

Recognition of decision problem is a perception of currently situations that come from the interpretation of information related to the problem. Information inputs play an important role in nontrivial decision making.

The river Mlava is tributary of Danube with the river basin of 1,860 km^2 located southeast from Belgrade, the capital of Serbia. This basin has relatively good status of water quality. Of particular interest is the sub-basin in the Gornjak gorge and upstream that was named “Gornjak Water Resources System” (GWRS) with the area of 700 km^2. There is a surface water station “Gornjak” at river kilometer 82.3 (from the river mouth). The average flow at this cross section is 7.3 m^3/s and the minimum flow $Q_{\min}$ 95% is 0.81 m^3/s.

The Gornjak Monastery of high historical value is situated in the beautiful Gornjak gorge. The monastery was built by Prince Lazar in 1379. Its church is devoted to the Presentation of the Most Holy Mother of God and built along the very rock. In the cave above the church is the saintly Gregory’s chapel. Downstream of the monastery one comes across the ruins of a monastery that rather resembles a fort. This is the Blagovestenje Monastery, an endowment of Despot Stefan Lazarevic of the fourteenth century. It used to host up to 400 monks. The Mitropolija Monastery is situated in a rock under Mali Vukan.

The Homolje region is characteristic for its lack of roads. The sole regional road traverses from Petrovac, through the Gornjak gorge to Zagubica. The source of the Mlava River is a karst spring (0.29–14.8 m^3/s, the famous Vrelo Mlave near Zagubica at river kilometer 105.

The municipality of Zagubica possesses many natural springs and they are not interested in using water from Mlava for water supply. There is a deficit of water sources in the region downstream of the Gornjak gorge, where the interest comes from. The development of the GWRS regional water supply system will require regulation of wastewater discharges into the watercourses and effluent discharge standards must be imposed according to the water quality objectives. The municipality of Zagubica may consider this GWRS development as a problem constraining the local development. The major economic activity is agriculture. Some losses of agricultural land should be compensated by a development in the industrial sectors and tourism.

The decision problem is to resolve these conflicts between various factors and stakeholders in the regional management process. A stakeholder in this context refers to an individual, organization, or institution that has a stake in the outcome of decision, beings either directly affected by the decision or having the power to influence or block the decision.

3 Decision Elements

Four basic elements are involved in decision making: alternatives, criteria, outcomes, and preference. In this example the alternatives could be generated by varying three system parameters, number of dams, dam site and dam height. Constraints are seen as high-priority objectives, which must be satisfied in the alternatives designing process. There are potential reservoir sites in the GWRS basin, four on Mlava and several on its tributaries (Dubocica, Osanica, Breznica, Krepoljin River). The comprehensive analysis of 13 alternatives of reservoir system was performed. The reservoir systems consist of one, two or three reservoirs. The set of alternatives was reduced, and six alternatives were selected for the second planning phase.

- A.1 The alternative A1 is the reservoir Vukan with normal level of 215 m a.s.l. and useful storage of 86 10^6 m^3 could provide 4.08 m^3/s (average) for planed regional water supply. The dam site is 1.5 km downstream of the monastery Gornjak, and the implementation would require the removal of the monastery. There will be a loss of agricultural land of 120 ha. A section (1.5 km) of the regional road and parts of local roads will be flooded by the reservoir.
- A.2 Reservoir Vukan with normal level of 205 m.a.s.l. and useful storage of 40 10^6 m^3 would have less social and environmental impacts on local areas and could provide 2.87 m^3/s for water supply. It requires the removal of the monastery Gornjak. The loss of agricultural land is less than alternative A1.
- A.3 Reservoir Vitman I with normal level of 215 m.a.s.l. could provide 2.97 m^3/s. The dam site is 3 km upstream of the monastery Gornjak, but there will be a loss of agricultural land (120 ha).
- A.4 Reservoir Gradac with normal level of 275 m a.s.l. could provide 2.73 m^3/s. The dam site is in the gorge Ribarska, upstream of the Gornjak gorge. There will be an impact on agricultural area in the region of Zagubica (a loss of 300 ha). The area of several households in two villages will be flooded and they have to be removed.
- A.5 System of three reservoirs, Vitman II (205) and Gradac (251) on Mlava, and Dubocica (255) on the tributary, could provide 2.5 m^3/s. All three dam sites are upstream of the monastery Gornjak. The loss of agricultural is relatively small since normal levels are lower.
- A.6 System similar to the alternative A5, Vitman III (203), Gradac (251) and Dubocica (255), which could provide 2.74 m^3/s. The Vitman III dam site is shortly downstream of Vitman II.

To evaluate the impacts to the society and to the environment in a comprehensive manner the criteria are used to capture relevant foreseeable impacts in their most appropriate and representative units. In this engineering project the criteria should represent public safety, social environment, natural environment, economy, culture, and politics. Four criteria are defined as follows.

f1. Investment costs (in 10^6 US$) including dam construction, expropriation of the area occupied by the reservoir, construction of new buildings for the households which have to move, and building new roads that will substitute flooded sections.
f2. Water supply discharge - yield (m^3/s) is the average annual value of discharge from the reservoir system available for regional water supply. The required reservoir capacity has been determined by the "sequent peak" algorithm for required total water demands. Water supply discharge has been determined by simulation of reservoir system with required capacity using historical hydrological series. Beside this discharge each reservoir has to realize downstream a biological minimum flow.
f3. Social impact (%) on urban and agricultural area expressing local regret as percentage of the regret in the alternative with maximum social impact.
f4. Impact on the monastery Gornjak is graded by the experts. The worst grade has the alternative that required the removal of monastery. The construction of a dam could have impact on ambient beauty of the Gornjak gorge.

The multicriteria task is to minimize the criterion functions f1, f3, and f4, and to maximize function f2. The four criterion functions are expressed in different units and they are noncommensurable.

The evaluation of alternatives (outputs) should be performed according to each criterion. "Quantitative" evaluations are performed by economic methods (f1) and by engineering methods (f2 and f3). "Qualitative" evaluations are performed by the experts (f4). By the comprehensive study of the alternatives the values of criterion functions are obtained. These performance values are presented in Table 1.

Most multicriteria methods require definition of quantitative weights for the criteria, to assess the relative importance of the different criteria. These weights do not have a clear economic significance. The use of weights gives us the opportunity to model the real aspects of decision making (the preference structure). "Equal importance" weights should be used either when there is no information from the decision maker (DM) or when there is not enough information to differentiate the relative importance of criteria. Within an entropy context this case represents total ignorance about criteria preferences. "Given" weights should be used when the DM has a good knowledge about criteria, in terms of their values and of their relationships. Very often, it is not easy to get the values of weights, therefore,

Table 1 Performance matrix

Name	Criteria		Alternatives					
	Unit	Extr.	A1	A2	A3	A4	A5	A6
f1. Investment costs	10^6 $	Min	40.01	21.06	25.87	46.89	33.33	33.86
f2. Water supply	M^3/s	Max	4.08	2.87	2.97	2.73	2.50	2.74
f3. Social impact	%	Min	47	6	42	62	6	6
f4. Impact on the monastery	Grade	Min	10	10	1	0	2	3

rationalizing and using proven elicitation techniques to help the DM express his preference, is an important aspect of multicriteria decision making. The weight assessment procedure could be performed by getting data from the experts. The AHP method could be used to build a hierarchy for deciding the belonged-relation at various levels of criteria and subcriteria and the weights can be estimated according to the hierarchy (Saaty 1980).

The given values should be analyzed in order to test the representativness of the mean values. Good procedure includes making histograms of the data to check the form of their distribution before proceeding with weighted average rating. The shape of the distribution is best communicated through visual displays. The measures of a distribution's deviation could be used, such as standard deviation, coefficient of variation, skewness, and kurtosis. The small values of these measures (close to 0) indicate the consensus among the evaluators. Large negative kurtosis shows that the evaluators are far from consensus. If the data are not normally distributed, and the measures of spread are not small, the average value is not representative. If the measures of shape are large (negative kurtosis) for the criteria weights, the sensitivity analysis covering the range of weights should be performed within multicriteria decision making procedure.

In our case study the preference structure is simulated by different values of weights (different scenarios of decision making), since it was not possible to involve decision maker (at republic level) to assess the preference. The weight stability intervals are determined by the VIKOR program (step 6 in the Appendix), and they could help in perceiving the influence of weights on the proposed (compromise) solution. The trade-offs analysis is an alternative way of considering preference (see Section 5).

Information inputs play a very important role in decision making. By information we mean any message that can potentially affect the generation of alternatives, decision criteria, outcomes and preferences. The solicited information may come from information systems or from consultation with experts and stakeholders (Rajasekaram and Nandalal 2005). Many papers are devoted to creating and transferring knowledge (Lapre and Van Wassenhove 2001). Political actors frequently face choice problems in which they have imperfect knowledge about the likely results of their decision. The information that could improve a decision maker's knowledge comes from "engineering level". The information gathering takes place over time, and it can be obtained only at some cost in time, effort or resources (Calvert 1989). The decision maker has two reasons to limit information gathering: to avoid high information costs; and to hasten the positive effects from the decision if the alternative "do nothing" is evidently inferior.

For each decision problem a competence set for its effective solution is needed (Yu and Zhang 1990). The true competence set consisting of ideas, knowledge, skills, attitudes, information and resources truly needed to successfully solve problem. The perceived competence set is a competence set as perceived by the decision maker. The gap between these two forms of a competence is due to ignorance, uncertainty, illusion and wishful thinking. Wisdom and certainty would lead to a high quality decision, and illusion and ignorance could lead to a low quality decision. The competence set related to the problem should expand if the existing competence set is incapable to solve the problem. A model to expand the competence set based on deduction graphs is presented in the work of Li and Yu (1994).

4 Compromising

Cooperation and compromising could resolve conflicts and ameliorate status reaching an agreement through mutual concessions. Understanding the conflict is primary in resolving process (Butler and Rothstein 2005). Several approaches to conflict resolution could be distinguished, based on cooperativeness and aggressiveness in resolving conflict (Wolf 2002). Compromise is cooperative and fair aggressive approach. Assuming necessity of cooperativeness and strive for some degree of aggressiveness in reaching fair (good) solution, compromising and collaborating could be considered as better approach acceptable in many cases (except violence). In compromise an agreement is established by mutual concessions. There should be a will to reach a mutually acceptable solution in which each person gets part of what they want. A stakeholder may have a high concern for his/her own group while concern over the other party declines to medium concern.

This paper roots for compromise. Cooperating and compromising is worthwhile when goals are clearly incompatible and mutually exclusive, decision makers have equal power, and partial satisfaction maybe better and feasible. Compromising is not acceptable when there is an imbalance in power of decision makers, or when sets of concerns are too important to compromise. To reach a compromise solution, the decision makers (parties or players) must have appropriate skills and knowledge. The preference of each player (decision maker) is based on his/her “Habitual Domain” and “competence sets”, a concept proposed by Po-Lung Yu (1990). For instance, “gambler” and “risk aversion” decision maker could have different preferences. The authors Hanany et al. (2005) argue that risk-aversion of at least one party explains the situation when conflict resolution ends in a bargained agreement. Cooperation and negotiation, emphasizing the similarities and reducing dissimilarities will help to solve problems (Yu 1990). In negotiations, the parties realize the potential of a compromise and can assess its main features. This can be supported with MCDM-based methods and tools (for example, the VIKOR method). When negotiations reach an impasse, final arbitration is often imposed to determine a settlement. But it seems that arbitration is rarely necessary in practice because of cost in time, effort or resources.

The allocation of water in the Mlava river basin is a complex management problem, with conditions that may foster conflicts. Managing water resources conflicts involves multiple issues and institutions having different objectives and responsibilities. Within this case study, the following institutions were involved:

- The Water Resources Fund of Serbia as main investor
- The Regional Water Authority (in Smederevo) interested in regional water supply
- Zagubica community asking for minimal social impact and compensation for local losses
- The Institute for the Protection of the Cultural Monuments

The Faculty of Civil Engineering, University of Belgrade, working on the Mlava project initiated negotiation process. The Faculty as the leading academic institution in the country in civil and environmental engineering had necessary authority to capture attention of stakeholders from the beginning in order to avoid emerging disagreements. The convener (Faculty) coordinated cooperation with active involvement of stakeholders that agree to work together to identify problems, define criteria, and identify alternatives.

In complex situation of this nature, the availability of decision support tool that could convey the technical information to stakeholders in an understandable form is vital for the success of a water conflict resolution. With an appropriate method and information tool the engineers are more effective in their attempts to help decision makers achieve an acceptable compromise (Schwarz 1994; Thiessen et al. 1998; Simonovic and Fahmy 1999).

Multicriteria analysis can provide decision aid in a negotiation process. A Pareto optimality analysis could identify conflicts between criteria. By definition, a solution $x^+ \in X$ is a Pareto optimal (noninferior) solution if and only if there is no $x \in X$ for which $F(x) \geq F(x^+)$ and $f_i(x) > f_i(x^+)$ for at least one i [$F(x)$ is a vector criterion function]. An assumption is that the criterion functions represent benefits. If a criterion function $f(x)$ represents cost, it should be minimized. The alternatives A2, A1, A2 = A5 = A6, A4 are the best ranked by single criterion f1, f2, f3, f4, respectively. The sets of Pareto optimal solutions are obtained analyzing data from Table 1 for different set of criteria. The results provide information for decision making, although the set of six alternatives in this example could not be reduced since all alternatives are Pareto optimal. The compromising then becomes one of choosing a compromise from these alternatives.

This paper focuses on a compromise solution obtained by a multicriteria decision making (MCDM) method. The most MCDM methods are based on comparisons and outranking or ranking the alternatives. A good compromise could be reached by a method based on the concordance-discordance principle. This principle consists in declaring that an alternative *a* is at least as good as an alternative *b* if:

A majority of the criteria (attributes) supports this assertion (concordance condition), and

The opposition of the other criteria (the minority) is not "too strong" (non-discordance condition).

Such method named VIKOR has been developed to solve a discrete decision problem with noncommensurable and conflicting criteria.

5 Compromise Solution by the VIKOR Method

The VIKOR *vikor* method in comparison with the TOPSIS method and the extended version in comparison with outranking methods are presented in the works by Opricovic and Tzeng (2004, 2007). This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria. The compromise solution is an alternative that is the closest to the ideal**.** An aggregating index (Q in Eq. 3, see Appendix) has been introduced as a measure of closeness. Previously, the L_p-metric has been introduced in compromise programming method (Yu 1973; Escobar and Moreno-Jimenez 2002). The merit L_1 represents the sum of all individual regrets (disutility), and L_∞ the maximal regret that an individual could have (Duckstein and Opricovic 1980). The algorithm VIKOR is presented in the Appendix.

The results by the VIKOR algorithm with data from Table 1 and equal weights $w_i = 0.25, \forall i$, are presented in Table 2.

Table 2 VIKOR results

	A1	A2	A3	A4	A5	A6
S_j – "group utility"	0.616	0.441	0.408	0.714	0.419	0.411
R_j – "individual regret"	0.250	0.250	0.176	0.250	0.250	0.212
Q_j – aggregating index	0.801	0.444	0.0	1.0	0.397	0.190

There is a set of compromise solutions consisting of

A 3. Vitman I (215), and
A 6. Vitman III (203), Gradac (251), Dubocica (255)

since they are "in closeness" (see algorithm step 5 in Appendix).

The weight stability intervals (the step 6) show that the compromise solution will change if weight w_3 would increase at least 20%.

The VIKOR method (the step 7) determines the following tradeoffs: 16.35 10^6\$/(m^3/s), 0.46 10^6\$/% and 2.58 10^6\$/mark-unit, for example, 1 m^3/s of water supply discharge worth as 16.35 10^6\$ of investment costs, and removing monastery Gornjak worth as 25.8 10^6\$. The first trade-off (0.03\$/m^3) could match economic trade-off that exists in the region. Second and third values seem too high in economic sense, although assessing trade-offs between economic and qualitative criteria is a very difficult task. The trade-offs determined by VIKOR are the result of normalizing noncommensurable criteria (Eqs. 1 and 2).

A second iteration was with new weights (0.2, 0.2, 0.3, 0.3) emphasizing preference of local stakeholders and of Serbian Orthodox Church. The VIKOR result is set of compromise solution

A 6. Vitman III (203), Gradac (251), Dubocica (255)
A 5. Vitman II (205), Gradac (251), Dubocica (255)
A 3. Vitman I (215)

The compromise solutions (in two iterations) are the base for negotiation. The decision makers' preference has been included by criteria weights. The VIKOR method proposes solution that provides a maximum group utility of the "majority" [represented by min S, Eq. 1 in Appendix), and a minimum individual regret of the "opponent" (represented by min R).

As the result of compromising and negotiation, the alternative A6 was chosen as a candidate for final solution. This compromise solution is a system of three reservoirs, two on the River Mlava and one on the tributary Dubocica. An additional good feature of this alternative is flexibility of system development. The system could be developed in three phases. First, the reservoir Vitman with normal level of 203 m a.s.l. could provide 1.3 m^3/s for regional water supply. The system would be expanded with reservoir Gradac (251), and 1.75 m^3/s water for water supply could be provided. In the third phase additional reservoir on the tributary could provide water for potential deficit in the Region (in the year 2020).

The following (ad hoc) comparative analysis shows the effects of compromising in this example. The annual average river flow of the River Mlava is 7.3 m^3/s. Regional water supply with 4.08 m^3/s could be provided by large reservoir Vukan (215). But, this solution is conflicting with social and cultural features and is opposed by local stakeholders. The compromise solution is the system of three (smaller) reservoirs, providing total discharge 2.74 m^3/s that is 67% of discharge by Vukan (215) with 1.26 times higher cost of m^3 for water supply. The compromise solution is costly \$ 12.8 10^6 more than the alternative Vukan (205) that provides similar water supply discharge (2.87 m^3/s), but the monastery Gornjak stays at its historical place and local regrets are minimized.

6 Discussion and Conclusion

Cooperation and negotiation, emphasizing the similarities and reducing dissimilarities will help to solve decision problems. Compromising is necessary when goals are clearly incompatible and mutually exclusive, decision makers have equal power, and partial satisfaction maybe better and feasible. In negotiations, the parties realize the potential of a compromise and can assess main features of the agreement established by mutual concessions. Compromising can be supported by MCDM-based methods and tools, such as the VIKOR method applied for the GWRS (Gornjak Water Resources System) decision problem. The VIKOR method assumes all parties acting as one rational decision maker in compromising, and the preference is expressed by the weights of criteria. The obtained compromise solution could be approved by the decision makers because it provides a maximum group utility of the “majority” and a minimum individual regret of the “opponent”. The main contributions of VIKOR to conflict resolution are: consideration of the decision making process in addition to the result; the use of criteria which is more meaningful for decision makers than utilities; search for the set of compromise solutions rather than one solution; and, interactivity which allows decision makers to participate in and control the decision process (by weights).

Consensus is popular as a democratic form of decision making, although it takes time and uses resources before a decision is made. The compromise solution for the GWRS decision problem is costly (financially) but creates commitment to the decision and could facilitate implementation.

In the next planning phase a sustainability of the solution should be considered. The obtained compromise solution should provide sustainable development through the process of managing social demands without eroding life support properties or mechanisms of social cohesion. Sustainable system should continue its productive potential for a long time (several decades) under a particular management practice. Sustainability of the GWRS solution could be assessed by scenarios analysis studying the solutions behavior under different assumptions about the future. A major issue is to identify which random variables and events are most important, in this example they could be water demands, migrations, local social and national political preferences.

The main activities for the implementation of the GWRS solution will take place in the context of river basin management project led by local authorities. It is necessary to establish an integrated monitoring and management system for all waters within the Mlava basin in order to maintain high status of waters defined by the EU Water Framework Directive (2000).

Acknowledgements This paper is a result of the project 144035A “Resolving Complexity, Fuzziness, Uncertainty, Conflict” which is funded by the Ministry of Science of Serbia. The constructive comments of the editor and the reviewers are gratefully acknowledged.

Appendix

The VIKOR method has been developed to solve the following problem

$$\underset{j}{mco}\left\{\left(f_{ij}\left(A_j\right),\ j=1,\ldots,J\right),i=1,\ldots,n\right\}$$

where: J is the number of feasible alternatives; $A_j = \{x_1, x_2 \ldots\}$ is the j-th alternative obtained (generated) with certain values of system variables x; f_{ij} is the value of the i-th criterion function for the alternative A_j; n is the number of criteria; *mco* denotes the operator of a multicriteria decision making procedure for selecting the best (compromise) alternative in multicriteria sense.

The algorithm VIKOR has the following steps:

(1) Determine the best f_i^* and the worst f_i^- values of all criterion functions, $i = 1,2,\ldots,n$;

$$f_i^* = \max_j f_{ij},\ f_i^- = \min_j f_{ij},\ \text{if the } i\text{-th function represents a benefit;}$$

$$f_i^* = \min_j f_{ij},\ f_i^- = \max_j f_{ij},\ \text{if the } i\text{-th function represents a cost.}$$

(2) Compute the values S_j and R_j, $j = 1,2,\ldots,J$, by the relations

$$S_j = \sum_{i=1}^{n} w_i\left(f_i^* - f_{ij}\right)\big/\left(f_i^* - f_i^-\right) \tag{1}$$

$$R_j = \max_i\left[w_i\left(f_i^* - f_{ij}\right)\big/\left(f_i^* - f_i^-\right)\right] \tag{2}$$

where w_i are the weights of criteria, expressing the DM's preference as the relative importance of the criteria.

(3) Compute the values $Q_j, j = 1,2,\ldots,J$, by the relation

$$Q_j = v\left(S_j - S^*\right)\big/\left(S^- - S^*\right) + (1-v)\left(R_j - R^*\right)\big/\left(R^- - R^*\right) \tag{3}$$

where $S^* = \min_j S_j$, $S^- = \max_j S_j$, $R^* = \min_j R_j$, $R^- = \max_j R_j$; and v is introduced as a weight for the strategy of "the majority of criteria" (or "the maximum group utility"), whereas $1 - v$ is the weight of the individual regret. These strategies could be compromised by $v = 0.5$, and here v is modified as $v = (n+1)/2n$ (from $v + 0.5(n-1)/n = 1$) since the criterion (1 of n) related to R is included in S, too.

(4) Rank the alternatives, sorting by the values S, R and Q in decreasing order. The results are three ranking lists.

(5) Propose as a compromise solution the alternative $[A^{(1)}]$ which is the best ranked by the measure Q (minimum) if the following two conditions are satisfied:

C1. "Acceptable Advantage":

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ$$

where: $A^{(2)}$ is the alternative with second position in the ranking list by Q;

$$DQ = 1\big/(J-1).$$

C2. "Acceptable Stability in decision making":
The alternative $A^{(1)}$ must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus" $v \approx 0.5$, or "with veto"($v < 0.5$). Here, v is the weight of decision making strategy of maximum group utility.
If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied, or
- Alternatives $A^{(1)}$, $A^{(2)}$,..., $A^{(M)}$ if the condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

(6) Determine the weight stability interval $\left[w_i^L, w_i^U\right]$ for each (i-th) criterion, separately, with the initial (given) values of weights. The compromise solution obtained with initial weights (w_i, i = 1,..., n), will be replaced at the highest ranked position if the value of a weight is out of the stability interval. The stability interval is only relevant concerning one-dimensional weighting variations.
(7) Determine the trade-offs, $tr_{ik} = \left|(D_i w_k)/(D_k w_i)\right|, k \neq i, k = 1, \ldots, n$, where tr_{ik} is the number of units of the i-th criterion evaluated the same as one unit of the k-th criterion, and $D_i = f_i^* - f_i^-$, $\forall i$. The index i is given by the VIKOR user.
(8) The decision maker may give a new value of tr_{ik}, $k \neq i$, $k = 1,\ldots,n$ if he or she does not agree with computed values. Then, VIKOR performs a new ranking with new values of weights $w_k = \left|(D_k w_i tr_{ik})/D_i\right|, k \neq i, k = 1, \ldots, n$; $w_i = 1$ (or previous value). VIKOR normalizes weights, with the sum equal to 1. The trade-offs determined in step 7 could help the decision maker to assess new values, although that task is very difficult.
(9) The VIKOR algorithm ends if the new values are not given in step 8.

The results by the VIKOR method are rankings by S, R, and Q, proposed compromise solution (one or a set), weight stability intervals for a single criterion, and the trade-offs introduced by VIKOR.

The extended VIKOR method in comparison with three multicriteria decision making methods TOPSIS, PROMETHEE, and ELECTRE is presented in the work of Opricovic and Tzeng (2007).

References

Babel MS, Das Gupta A, Nayak DK (2005) A model for optimal allocation of water to competing demands. Water Resour Manage 19:693–712. doi:10.1007/s11269-005-3282-4

Bell DE, Raiffa H, Tversky A (eds) (1985) Decision making: descriptive, normative, and prescriptive interactions. Cambridge University Press, Cambridge

Bogardi JJ, Nachtnebel HP (eds) (1994) Multicriteria decision analysis in water resources management, international. Hydrological program, UNESCO, Paris

Butler LCT, Rothstein A (2005) On conflict and consensus. http://www.consensus.net

Cai X, Lasdon L, Michelsen AM (2004) Group decision making in water resources planning using multiple objective analysis. J Water Resour Plan Manage 130(1):4–14. doi:10.1061/(ASCE)0733-9496(2004)130:1(4)

Calvert R (1989) Political decision making with costly and imperfect information. Math Comput Model 12(4/5):497–509. doi:10.1016/0895-7177(89)90420-2
Duckstein L, Opricovic S (1980) Multiobjective optimization in river basin development. Water Resour Res 16(1):14–20. doi:10.1029/WR016i001p00014
Escobar MT, Moreno-Jimenez JM (2002) A linkage between the analytic hierarchy process and the compromise programming models. Omega 30:359–365. doi:10.1016/S0305-0483(02)00053-1
Hajkowicz S, Collins K (2007) A review of multiple criteria analysis for water resource planning and management. Water Resour Manage 21:1553–1566. doi:10.1007/s11269-006-9112-5
Hanany E, Kilgour M, Gerchak Y (2005) How the prospect of final-offer arbitration affects bargaining. http://www.eng.tau.ac.il/~hananye /BFOA.pdf
Hyde KM, Holger R, Maier HR, Colby CB (2004) Reliability-based approach to multicriteria decision analysis for water resources. J Water Resour Plan Manage 130(6):429–438. doi:10.1061/(ASCE)0733-9496(2004)130:6(429)
Just RE, Netanyahu S (1998) Conflict and cooperation on trans-boundary water resources. Kluwer, Dordrecht
Lapre MA, Van Wassenhove LN (2001) Creating and transferring knowledge for productivity improvement in factories. Manage Sci 47:1311–1325. doi:10.1287/mnsc.47.10.1311.10264
Li HL, Yu PL (1994) Optimal competence set expansion using deduction graph. J Optim Theory Appl 80:75–91. doi:10.1007/BF02196594
McNulty H (1986) The importance of the hundredth meridian to the uses and management of water. In: Cairns J, Patrick R (eds) Managing water resources. Praeger, New York, pp 100–116
Opricovic S, Tzeng GH (2004) The compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS. Eur J Oper Res 156(2):445–455. doi:10.1016/S0377-2217(03)00020-1
Opricovic S, Tzeng GH (2007) Extended VIKOR method in comparison with outranking methods. Eur J Oper Res 178(2):514–529. doi:10.1016/j.ejor.2006.01.020
Rajasekaram V, Nandalal KDW (2005) Decision support system for reservoir water management conflict resolution. J Water Resour Plan Manage 131(6):410–419. doi:10.1061/(ASCE)0733-9496(2005)131:6(410)
Raju KS, Duckstein L, Arondel C (2001) Multicriterion analysis for sustainable water resources planning: a case study in Spain. Water Resour Manage 14:435–456. doi:10.1023/A:1011120513259
Saaty TL (1980) The analytic hierarchy process. McGraw-Hill, New York
Schwarz RM (1994) The skilled facilitator: practical wisdom for developing effective groups. Jossey-Bass, San Francisco
Simonovic SP (1996) Decision support systems for sustainable management of water resources: general principles. Water Int 21(4):223–232
Simonovic SP, Fahmy H (1999) A new modeling approach for water resources policy analysis. Water Resour Res 35(1):295–304. doi:10.1029/1998WR900023
Srdjevic B, Medeiros YDP, Faria AS (2004) An objective multi-criteria evaluation of water management scenarios. Water Resour Manage 18:35–54. doi:10.1023/B:WARM.0000015348.88832.52
Thiessen EM, Loucks DP, Stedinger JR (1998) Computer-assisted negotiations of water resources conflicts. Group Decis Negot 7(2):109–129. doi:10.1023/A:1008654625690
Water Framework Directive (2000) Directive 2000/60/EC of the European Parliament and of the Council, L 327/1. Official Journal of the European Communities EN, Luxembourg
Wolf AT (2002) Conflict prevention and resolution in water systems. Edward Elgar, Cheltenham, UK
Yu PL (1973) A class of solutions for group decision problems. Manage Sci 19(8):936–946
Yu PL (1990) Forming winning strategies: an integrated theory of habitual domains. Springer, Heidelberg
Yu PL, Zhang D (1990) A foundation for competence set analysis. Math Soc Sci 20:251–299. doi:10.1016/0165-4896(90)90005-R
Zadeh LA (1963) Optimality and non-scalar-valued performance criteria. IEEE Trans Automatic Contr AC 8(1):59–60. doi:10.1109/TAC.1963.1105511
Zarghaami M (2006) Integrated water resources management in Polrud irrigation system. Water Resour Manage 20:215–225. doi:10.1007/s11269-006-8048-0