NEGOTIATION SUPPORT SYSTEM FOR RESOLUTION OF DISPUTES OVER INTERNATIONAL WATER RESOURCES

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Abstract: Conflicts over international waters are, in many cases, caused by potential or actual water scarcity. It has been proven that inefficient management of water resources can cause artificial water scarcity, and that concepts of water markets have a potential to increase the efficiency of water utilization. The water-market approach aims at determining an efficient allocation of water resources based on a system of voluntary trade in water, which brings potentially large benefits to all parties involved. A Negotiation Support System is proposed, which introduces a combination of an economically based water allocation optimization model, decision support tools, and some concepts of Game Theory into negotiations over international water disputes.

Keywords: International waters, Negotiations, Decision Support

1. INTRODUCTION

Available quantities of the naturally renewable fresh waters are being exhausted in many parts of the world, and the problem of international water resources is becoming more acute. International or shared waters are surface and underground water resources whose watersheds are spread over the territory of more than one country. Most of the world's largest rivers cross or define international borders. There are more than 260 international river systems, with over 50 percent of the world's global population (12). Many of the world's aquifers are spread under the territory of more than one country (10). When dealing with water shortages, governments frequently take unilateral actions, without considering the needs of their neighbors. Such policies alter the natural balance of quantities and qualities of water resources and, eventually, cause international disputes. Management of international waters is difficult, since issues of control, jurisdiction and sovereignty are extremely complicated. International Law (11) does not provide unambiguous directive for appropriation and management of international water resources. When claiming rights to shared waters, nations rely on their geographical position, historical rights, and often on their relative power.

Conflicts over international waters are extremely complex because of the variety of interests involved and the meanings of water to human society. In some countries water is a matter of culture and religion, often an issue of survival or of economic prosperity, but in most parts of the world it is not merely the scarcity that makes water an important resource. Water resources are of strategic importance and become a matter of a country's highest policy. Conflicts over international waters are long lasting, often involving military threats and sometimes even military skirmishes, although not wars (13).

Negotiations over allocation of shared water resources are frequently a long-drawn process, burdened by mutual mistrust among the parties. Water quantity is often the dominant feature of the negotiations, even though there are many other aspects which deserve consideration, such as quality and environmental amenities, and thus dividing the waters is viewed as a win-lose situation. Negotiations over shared waters are in most cases conducted as simple, distributive bargaining processes. If a solution is reached, it may be heavily influenced by the power balance between the parties, and at least one of them leaves the table unsatisfied.

This work is concerned with competition over shared international water resources, under conditions of potential or actual water scarcity. It has been proven that inefficient management of water resources (such as under-pricing, over-pumping, etc.) can cause artificial water scarcity, and that water markets have a potential to increase the efficiency of water utilization (1),(4). The water market approach aims at determining an efficient allocation of water resources based on a system of voluntary trade in water, which can bring benefits to all parties involved.

The basic assumption of our work is that certain features of a water market system can help in adjusting the allocation of a disputed international water resource to actual hydrological, political and economic circumstances, while insuring improved benefits to the parties. We propose a collaborative Negotiation Support System (NSS) as a dispute resolution technique, to assist the parties in searching for feasible and satisfying solutions to managing the shared resource. A central component of the NSS is the Water Allocation System WAS (4) that allocates water in a way which maximizes total social net benefit from water supply to all consumers in a defined region.

2. VALUE OF WATER (FOLLOWING FISHER ET AL., 2002)

Most solutions to water allocation problems relate to water only in terms of quantities. Demands for water are projected according to needs of various consumers. Supplies of available water are estimated and whenever the balance between the two shows a shortage, engineering and/or political solutions are sought. According to this approach, water allocation between two parties that claim rights from the same water resource is perceived as a zero-sum game: water allocated to one party is not available to the other. This holds for both within-a-country and international water, since the parties can represent different types of demands in a single country or two states (or political entities) that share a water resource.

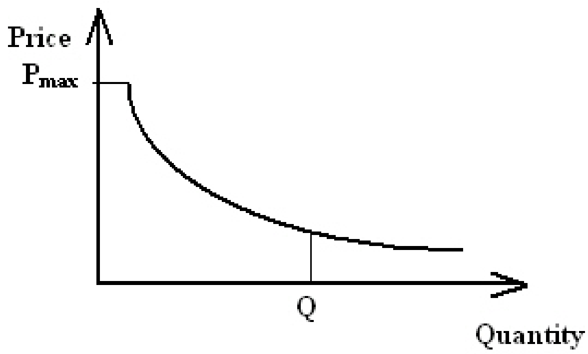

Fig. 1. Demand curve

In recent years, there have been attempts to relate to water in terms of values. They are based on the fact that water is valuable not only because it is essential for sustaining human life, but because it is scarce (2). In the countries that have access to the sea, desalination puts an upper bound to the value of water in dispute (4). *Feitelson and Haddad* (2001) give as an example the dispute over the Mountain Aquifer between Israel and the Palestinians. With desalination as an alternative water source, the value of the water in dispute is at most in the range of a few hundred million dollars per year - a sum that should be negotiable.

The economic value of water is expressed through the willingness of a user to pay for a certain amount of water. For the first few units of water one is willing to pay the highest price, as it will be used to satisfy the most urgent needs. Values of the following units of water decrease, since it is used to satisfy less essential needs. The willingness to pay as a function of the amount of water is presented by the *demand curve* (Figure 1).

When an amount of water, Q, is supplied to a user the total value of that amount of water to that user equals to the area below the demand curve, to the left of Q (P_{max} is a cutoff price, which makes the area finite).

Summation of demand curves of all users (urban, industrial or agricultural) in a specified region yields the aggregate demand curve for that region, and the area under the curve gives the benefits. These are gross benefits because there are costs of providing the amount Q of water. The ***cost function*** (Figure 2) is an increasing function of the amount of water, and may rise smoothly or in steps corresponding to different supply sources (4).

For any allocation Q the *net benefit* is calculated by subtracting the total costs of providing the

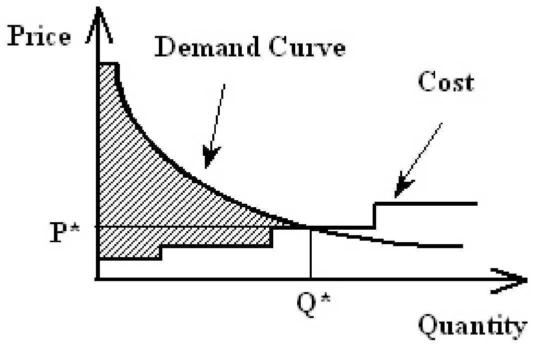

Fig. 2. Optimal allocation

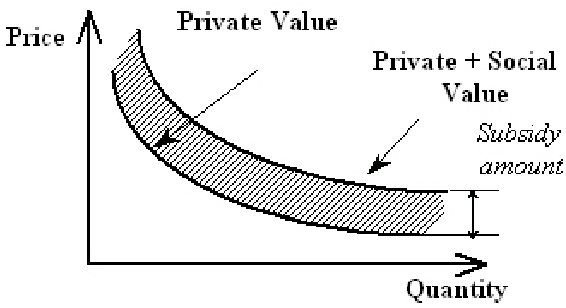

Fig. 3. Private and social value of water

water (the area under the cost curve, to the left of Q) from the gross benefits (the area under the demand curve to that point).

If the allocation is designed to maximize net benefits, the amount $Q*$ (given by the intersection of the two curves, in Figure 2) should be delivered. A lesser amount of water would mean that the consumer would be willing to pay more for additional units than the cost of such additional units. A greater amount of water delivered than $Q*$ would mean that the consumer would not be willing to pay the costs of providing the additional units.

Such demand curves capture the ***private value*** of water, the value to the consumer. But water also has a ***social value***, which can exceed the private one. For example, one of the ways for a government to support the agricultural sector is to subsidize its water. In the case of a subsidy by a fixed amount at all quantities, the demand curve would move up as shown in Figure 3. This means that this water is worth to society more than farmers are willing to pay for it. The optimal allocation is now determined as the intersection of the cost curve and the new demand curve.

Such a water policy would make farmers use more water than without the subsidy.

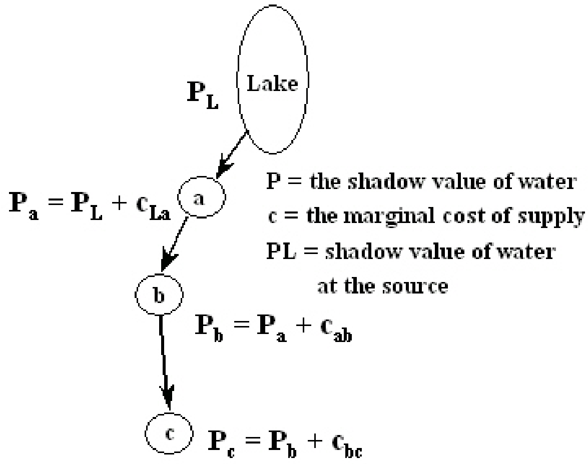

Fig. 4. Scarcity rent and shadow prices

2.1 Shadow prices and scarcity rents

Prices in competitive markets measure the willingness of buyers to pay for additional units of the goods in question (marginal value). When a price is higher than the cost of providing an additional unit (marginal cost), that unit is worth providing. A price less than the marginal cost means that production of that good should be cut back. This system of prices and the profits and losses is a guide for an optimal allocation of goods.

There are many reasons why the laws of perfect competitive markets can rarely be applied in the case of water. A competitive market assumes many private competing producers and buyers, but water is usually not supplied privately and competitively by many sellers. Other reasons are that pumping in one location may affect the availability or cost of water at another location of the same source (e.g., aquifer).

If, in Figure 2, $Q*$ were the maximum amount of water available, then, $P*$ would represent the price which consumers would be willing to pay to obtain an additional unit of water. This price is called the shadow price of water. It can also be defined as the amount of increase in net-benefit to water users that would result from the availability of that additional unit of water.

The shadow price of water at a given location is not necessarily equal to the direct (marginal) cost of producing it there. If demand from a limited water source exceeds its capacity then the water in the source has a value in situ, called scarcity rent. When direct costs of providing the water are zero, the scarcity rent equals the shadow price of water.

Accordingly, at a given location, the shadow price is the sum of the scarcity rent of water and the direct marginal costs of providing it at that location (Figure 4).

3. THE WATER ALLOCATION SYSTEM (WAS)

The methodology for optimal allocation of water has been embedded in the Water Allocation System (WAS) model (4). The area in question, covering the territory of one or more political parties, is divided into 'districts'. Each has sources, consumer sectors (urban, agriculture, industry, nature), and is connected to other districts or to a central conveyance system. Physical and economic data are given for the districts, consumer sectors, and the connecting conveyance system. The model maximizes the total net benefit by allocating water among all districts and sectors, subject to physical, political, administrative and any other imposed constraints. The model can also include recycling of wastewater.

Depending on the users' definition, water resources in the WAS model can be treated as common pools with respect to a group of consumers, so that there are no constraints on the allocation among them. Another possibility is to constrain the allocations by defining a minimum, maximum, or a fixed quantity of water to be allocated to particular consumers, districts, or countries (or any other political entities).

WAS can be run in a countrified version, where the area in question is a single country, with water inputs from sources shared with its neighbors *a priori* defined. Another option is to run WAS for the region of two or more countries (the regional version), in which case shared water resources are treated as common pools. Both types of WAS runs can be performed to reflect various sets of physical, political, administrative and other constraints. Each set of constraints produces a water allocation alternative (countrified or regional).

The set of WAS output data includes the optimal allocations, total net benefit from water use, shadow prices of water for the consumers and districts, shadow values of constraints, including scarcity rents for water in the sources.

4. OPTIMAL ALLOCATION OF WATER BETWEEN PARTIES

The basic principles of economically optimal water allocation serve as the basis for the proposed Negotiation Support System. Suppose that a total quantity Q of water is allocated to the two parties, A and B, in quantities Q_A and Q_B ($Q_A + Q_B = Q$), so that the marginal value of water to party A is higher than that of party B (Figure 5). For zero water supply costs, the total net benefit to A and B from using quantity Q of water is equal to the sum of the areas below the two demand curves. According to the principles outlined above, if a

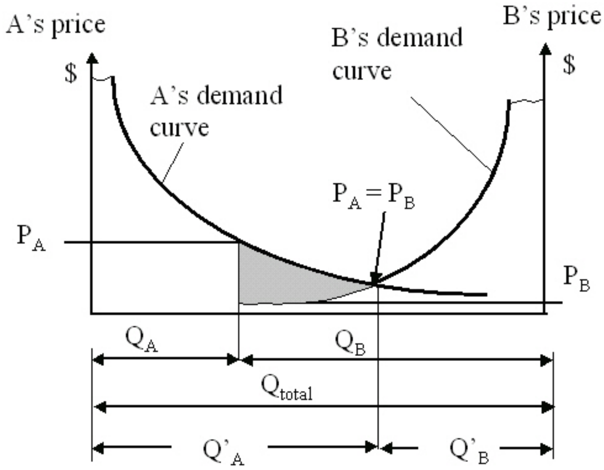

Fig. 5. Water transfer: creating a 'new' value

unit of water were transferred from party B to party A, the sum of the areas, i.e. the total net benefit, would increase. By transferring additional units of water from B to A, we continue to increase the total net benefit, reaching the maximum at the point at which the two marginal values, P_A and P_B, are equal. Hence, if we wanted to allocate the total quantity Q of water to A and B so as to maximize the total net benefit, the optimal quantities for allocation would be Q'_A and Q'_B. Relative to the starting allocation (Q_A and Q_B), the transfer of water from B to A increases the total value by the shaded area in Figure 5.

5. NEGOTIATION SUPPORT SYSTEMS

Negotiation support systems are designed to provide assistance in situations where there is disagreement among the parties which decision to adopt. They can be categorized according to their functions (5 , 9) as:

(1) Negotiations Preparation Systems, which assist each party to analyze its positions and to decide what choices to make during negotiations;
(2) Negotiation Information Management Systems that include
   - Context Support Systems, which simulate the behavior of the system that is the subject of negotiations, and can be used to analyze its performance under different circumstances (scenarios);
   - Process Support Systems, which are concerned with the dynamics of the negotiation process.

6. THE NEGOTIATION SUPPORT SYSTEM (NSS)

Our NSS is designed to support bilateral negotiations, although the same concepts can be extended to negotiations with more than two parties. The NSS is based on symmetry, and provides an identical set of tools to both parties. The negotiation is modeled as a combination of two processes: individual decision-making and joint problem solving. Individual decision support is aimed at assisting the parties in structuring their systems of preferences related to the water allocation problem. Each party establishes its utility for negotiated alternatives, using the AHP algorithm (6) to weight and combine its different objectives, with the economic objective being one of them, into a single utility figure. Joint problem solving is modeled as an interaction, supported by tools from game theory, in which the parties have the opportunity to design and select jointly preferred solutions.

The central component of the NSS is the WAS model which provides assistance in both individual and joint decision making (Figure 6). It supports interactive communication in two senses: first, each party can use the WAS alone, by introducing various water-allocation alternatives into the model, receiving feedback information about the implications of such alternatives on its country's domestic water economy and consequently on its other objectives. Second, the two parties can perform a WAS analysis jointly, in search of joint gains. While exploring alternatives for resolving the allocation of the joint water resources and negotiating 'around' the WAS model, the parties have an opportunity to improve communication, evaluate each other's expectations and goals, and interact in a manner that is less distributive and more integrative.

Within the framework of the NSS, the negotiation process is modeled as an alternating sequence of individual and joint activities by which the parties manipulate the set of alternative solutions, aimed at enlarging the negotiation space by creating and proposing new alternatives, and narrowing it by removing non-efficient ones. An alternative can be designed by a single party, by a mediator, or by the two parties jointly. Removal of non-efficient offers is determined by the individual preference structures and utility values of both parties, and by a game-theoretic device based on the Nash bargaining solution, which operates within the joint 'utility space'. Enlarging and narrowing the set of alternatives are repeated in an iterative manner, regulated by the protocol of interaction. The iterative nature of the negotiation process enables the parties to revise their preference structures during the negotiations and negotiate around a dynamic set of the alternative solutions, and is supposed to lead eventually to an agreed solution. The design of the NSS is based on conclusions drawn from a number of real-world cases of international water disputes. It recognizes the usual absence of confidence between the parties, and assures a level of confidentiality in the manipulation of revealed information. Also, the approach does not assume that agreement between the parties has to be based necessarily on cooperation in the management of the disputed water resources. It searches for the 'best outcome' as perceived jointly by both parties, given the level of their mutual trust, and given the present 'state of the world'.

6.1 Negotiation protocol (protocol of interaction)

Negotiation is a joint problem solving process during which the parties have to communicate and interact. The NSS includes an interaction protocol, designed to assist the parties in problem solving, since the quality of the outcome depends on the quality of the communication between them. Parties who claim rights to the same water resource presume, by themselves, to have mutually conflicting interests and are inclined to bargain in a distributive manner. The negotiators often find themselves locked in situations when it seems impossible to overcome the differences, and at least one of them prefers to break off the negotiation process. The protocol of interaction is aimed at reducing the probability that this will occur. It is motivated by normative (prescriptive) models of interaction, such as the models of Game Theory.

The protocol of interaction consists of the rules, which specify the steps of interaction. The protocol of a typical bargaining interaction is an alternating sequence of offers and counter-offers. In our approach, the negotiation protocol does not require an exchange of offers. In contrast, it prescribes a sequence of two procedures, alternative-generation and alternative-evaluation, aimed at searching for those negotiated solutions that improve the achievements for both parties. A new alternative solution may be offered by one or both parties, or by a mediator, disregarding the fact who offered the previous one. Generation of alternatives is supported by the WAS model which enables analysis of various inter- and intra-country water allocation alternatives. Each of the parties then conducts its own evaluation based on a pair-wise comparison of the proposed alternative negotiation solutions as well as other elements of the negotiators' preference structures. These two processes, alternative-generation and alternative-evaluation, are repeated in a sequence of iterations, which seeks to terminate when a stable solution is reached.

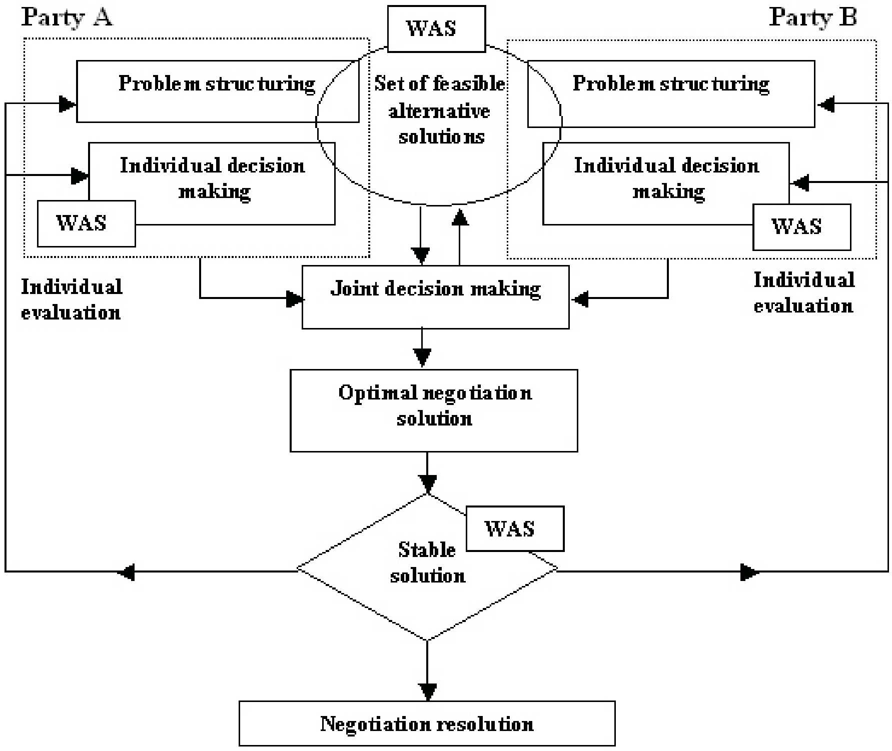

Fig. 6. Negotiation Support System

6.2 Design of alternatives

The parties design alternatives while interacting, individually or jointly, with the WAS model. Each party can analyze the effects of an alternative using the complete set of WAS outputs. However, there are only few results of the WAS output that are relevant on the public level and which figure in the bargaining process. Let:
Q_{DS} = the average annual renewable quantity of water in the disputed resource;
$Q_i(a)$ = quantity of water from the disputed resource, allocated to party i, $i = A, B$, in alternative a;
$q_i(a)$ = WAS-optimal quantity of water from the disputed resource, to be supplied to the consumers in i, given $Q_i(a)$ ($q_i(a) = Q_i(a)$). $q_i(a)$ can vary as a function of intra-country water allocation arrangements;
$V_i(a)$ = the annual net economic benefit of party i from the use of water as a result of the negotiation alternative a. It is the net benefit from the total annual consumption of water in i, when the annual available supply of water includes $q_i(a)$: $V_i(a) = V_i(Q_i' + q_i(a))$, where Q_i' is the annual renewable quantity of water available to i that is not subject of the negotiations. Like $q_i(a)$, $V_i(a)$ varies as a function of the domestic water arrangements.

In any negotiated alternative a, Q_{DS} can be allocated in one of the two following ways:

(1) it can be *a priori* allocated to the parties in quantities $Q_A(a)$ and $Q_B(a)$, (so that $Q_A(a) + Q_B(a) = Q_{DS}$), where each party analyzes the intra-country water-allocation alternatives *posteriori*, given $Q_i(a), i = A, B$;
(2) Q_{DS} can be defined as a common pool; in this case, the regional version of the WAS model determines the optimal allocation so as to maximize the joint net benefit from the annual water consumption in both countries - without any restrictions or pre-judgment on the final negotiated allocations. Allocated quantities of the disputed resource ($Q_A(a)$ and $Q_B(a)$) and the net benefit from the water use in the two countries will be different for different regional alternatives.

On a *public level* (in terms of shared information), the parties negotiate the allocation of two commodities: water and an economic value. From the perspective of party i, $i = A,B$, a negotiation alternative a is represented by the allocated quantity of water from the disputed resource, $Q_i(a)$, measured in units of volume, and a monetary value $v_i(a)$. The sum of the quantities allocated to the two parties, $Q_A(a) + Q_B(a)$, is constant over all the alternatives and equals the amount of water in the disputed source. Since water sources are always subject to random variability, this is usually set to be an agreed upon average annual renewable potential of the water source.

$v_i(a)$ is the net economic gain to party i from alternative a, relative to some reference alternative, a_r, assured to party i ($v_i(a) = V_i(a) - V_i(a_r)$). If, for example, alternative a reallocates the disputed water resource so that party A gains an additional quantity of water, the economic value of the total quantity of water available to A increases according to its demand curve. Correspondingly, party B loses the same quantity of water, so that the economic value of its available water decreases according to its own demand curve. If the gain to A is greater than the loss to B then they may agree to share in some manner the net total gain. In order to make such an alternative attractive to party B, A can offer B a side payment. $v_A(a)$ and $v_B(a)$ are then, the net economic values that the two parties gain by selecting alternative a over the reference alternative a_r. The sum $v_A(a) + v_B(a)$, varies over the alternatives. If alternative a is (economically) efficient, this sum will be equal to the change in the total annual economic value of water in the two countries, achieved by selecting alternative a over a_r.

On a *private level* (in terms of confidential information), each party evaluates the efficiency of alternative solutions to the problem according to a set of his own criteria. The set of criteria of one party is independent of the set of criteria of the other party. In terms of decision-making theory, these criteria are the parties' objectives or attributes. Party i can assess the 'quality' of alternative a by analyzing the 'performance' of the corresponding bundle, $(Q_i(a), v_i(a))$, with respect to each of his objectives. If $u_i^j(a)$ is a subjective measure (score) of the degree to which alternative a satisfies objective j, $j = 1,\ldots,n$, then, for party i, alternative a represents the n-tupple $[u_i^1(a), \ldots, u_i^n(a)]$, with n being the number of party i's objectives (criteria). The subjective measures, $u_i^j(a)$, result from an evaluation of alternative a, as part of i's individual decision making process, and are explained next.

6.3 Individual decision support

The negotiation framework is based on the idea of a dynamic evaluation of the objectives, which reflect the party's interests, goals, and perceptions. Generally, the objectives (criteria) can be of the two following types:

(1) Quantitative objectives, which can take values measurable in their characteristic units. For example, water quantity and economic efficiency (net benefit) from water use are objectives measured in units mcm and millions of dollars, respectively;
(2) Qualitative objectives that cannot be measured by any standard units, such as national security or social stability.

The dynamics in the set of the objectives is a function of the change in the negotiation conditions (e.g., knowledge, information, relationship and trust, previous proposals). For given negotiation conditions, a 'state of the world', and a set of L alternative solutions, party i, $i = A,B$, has a subjective utility function, U_i which assigns a single score to every n-tupple $[u_i^1(a_l), \ldots, u_i^n(a_l)]$, $l = 1,\ldots,L$. This score is a real number from the interval [0,1], which expresses the level of overall satisfaction that party i accords to each of the L alternatives.

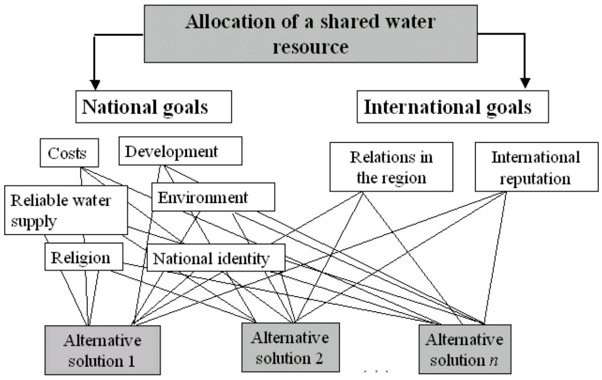

Fig. 7. Individual preference structure

Individual decision support consists of preference-setting procedures (performed by the party's decision maker) and calculations (performed with the tool for individual decision support). The final result of the quantitative and qualitative analysis is party's individual utility function, relevant for particular negotiation conditions. The model for individual decision support utilizes the Analytic Hierarchy Process (4), (7) for individual structuring (presentation and evaluation) of the water allocation problem. The AHP is a multi-objective decision support designed to select the best from a number of alternatives evaluated with respect to several criteria. It is suitable as decision support in this kind of water allocation problems, since it assists the decision maker in dealing with both quantitative and qualitative objectives. The AHP utilizes the assumption that human decision makers make good judgments for small groups of objects. It prescribes pair-wise comparisons of the elements of individual preference structure, organized in a hierarchical manner. These comparisons are used to develop overall priorities for ranking of the alternatives.

Within the framework of the NSS, the hierarchy of each party consists of three levels as shown by an example in Figure 7. The first level represents the overall aim of the party, the second lists the party's objectives (criteria) which are affected by the negotiation outcome, while the third level consists of the available negotiation alternatives.

The first and the third level of both parties' hierarchies are identical and publicly known at each stage of the negotiations. The elements of the second level, the set of criteria, as well as the

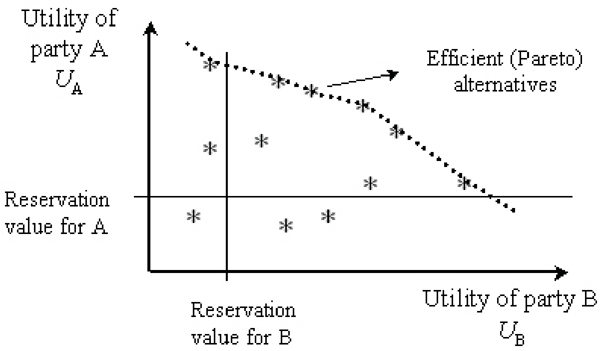

Fig. 8. Joint utility space

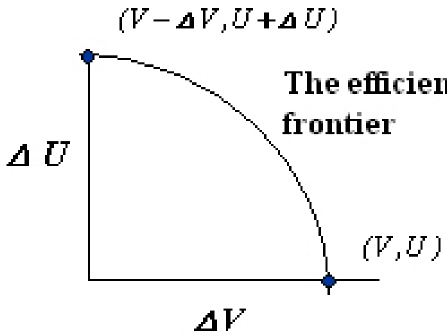

Fig. 9. The Nash rationale for the selection of the 'best' alternative

weights assigned by the party to the criteria and to alternatives vis--vis the criteria, are individual and confidential.

The individual utility function which describes the overall satisfaction of party i by alternative negotiation solution a, obtained by the AHP model, is of the linear additive form:

$$U_i(a) = w_i^1 u_i^1(a) + ... + w_i^n u_i^n(a), \sum_{j=1}^{n} w_i^j = 1$$

where $w_i^1, \ldots, w_i^n$ are the weights of n objectives (criteria), and u_i^j, j = *1,...,n* is the 'performance' of alternative a with respect to criterion *j*. Once party i has established its overall utility function, its individual objective becomes a standard optimization problem: find alternative a for which $U_i(a)$ will be maximized.

6.4 Joint consequence space

When parties have opposed interests, the solution, which maximizes the utility function of one party, will be unacceptable by the other. A negotiation agreement will be achieved only if the parties manage to find a jointly acceptable solution. Within the framework of the NSS, a Game Theory model is included, which assists the parties in selecting an efficient and equitable alternative, among the set of known, feasible alternative solutions to the problem.

Selection of the 'best' negotiation solution is performed by accounting for the utility functions of both parties. Once the parties have evaluated their utility functions for a given set of negotiation alternatives, their individual overall rankings can be presented in a joint utility space (Figure 8).

Reservation values in a joint utility space mark the utility values of the alternative assured to the parties in case one of them breaks away from the negotiations. In Negotiation Theory, this threshold value of the consequence of a 'no agreement' alternative is called BATNA - *the best alternative to a negotiated agreement*. In other words, a rational party, who acts to maximize his utility function, will not accept an alternative which gets him a utility value lower than his BATNA. Another constraint for the selection of the 'jointly best' alternative arises from the concept of *efficiency*. Of all feasible alternatives, the efficient ones are those from which one cannot move to improve the utility of one party without decreasing the utility of the other. These lie on the Efficient (Pareto) Frontier.

With these two constraints, the problem is reduced to the selection of one of the efficient alternatives, which are beyond the lines that mark the parties' reservation values. This is a difficult task, since by moving along the efficient frontier, improvement of one party's gains can be achieved only at the expense of other party's loses. Of the several Game Theory models which propose solutions for such difficulty, within the framework of our NSS, the Nash bargaining solution is adopted as the criterion for the selection of an efficient and equitable negotiation resolution.

According to the Nash solution, the best alternative is the one which belongs to the efficient frontier and maximizes the product of the utility values of the two parties. According to the rationale of the Nash point (Figure 9), the parties should move from the point (V, U) on the efficient frontier to point $(V\text{-}\Delta V,\ U\text{+}\Delta U)$ if $\Delta U/U$ is greater than $\Delta V/V$ (the proportional gain for one player is larger than the proportional loss for the other). They should continue to move along the frontier, up to the point at which $\delta U/U = -\delta V/V$, or, at which the product UV is maximized (8).

6.5 Iterative progress of the negotiations

The dynamic evolution of the set of alternative solutions can be shown as a progression in the joint consequence (utility) space (Figure 10). The

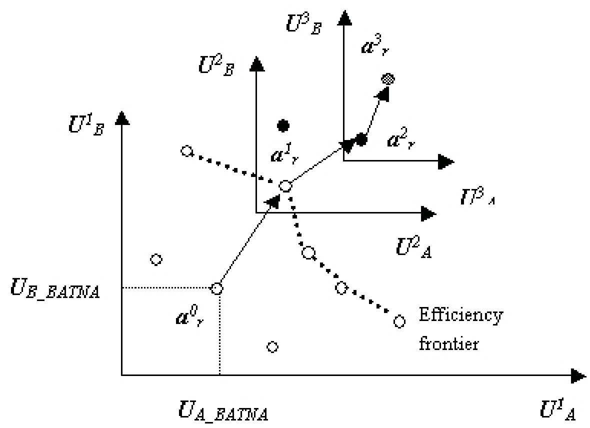

Fig. 10. Iterative process of negotiations

NSS is designed to assist the parties in advancing towards solutions which (jointly) improve their overall satisfaction. The utility function, as a measure of a party's overall satisfaction, is formulated based on that party's preference structure.

The NSS allows the parties to change their sets of objectives and systems of preferences, and hence the utility evaluations, in response to changes in the negotiation conditions. Stages of the negotiation process in which the negotiation conditions are constant are called iterations. In a new negotiation iteration, the parties can change their sets of the objectives by adding and/or removing objectives, and/or by changing their relative importance.

In Figure 10, U_A^t and U_B^t are utility values of parties A and B, in negotiation iteration t. In each iteration, the parties negotiate over a set of alternatives with the aim of (eventually) selecting a single alternative as 'the best' (proposed by the Nash bargaining solution). The alternative selected as the 'best' in one iteration is the reference alternative for the next iteration. This means that alternatives negotiated in iteration t are compared relative to one another, as well as to the reference solution selected as 'the best' in iteration *t-1*. In a general case, utility scores of a reference solution selected in iteration *t-1*, U_A^{t-1} and U_B^{t-1}, can be different from the utility scores of that same alternative in iteration t, U_A^t and U_B^t, since the utilities are re-evaluated for each iteration. The reference alternative of the first iteration is the 'no agreement' alternative, which corresponds to (U_{ABATNA}; U_{BBATNA}). If no alternative in iteration t has a better performance than the reference alternative a_r^{t-1}, then this solution is proposed as the final negotiation resolution.

6.6 Relaxing the weights of the criteria

For a given alternative a, which is supposed to challenge the stability of the last reference alternative a_r, the parties are allowed to 'relax' the weights of their objectives, by assigning an upper and a lower limit to the weight of each objective. The final weights of the objectives are then obtained by a maximization procedure.

Let w_A^i i = *1,...,n* and w_B^j, j = *1,...,m*, be the weights of the objectives of parties A and B in iteration t. Next, let $u_A^i(a)$ and $u_B^j(a)$, i = *1,...,n* and j = *1,...,m*, be the scores of alternative a with respect to n objectives of party A and m objectives of party B. Then, the product of the overall utilities of the two parties resulting from alternative a, is:

$$U_A(a) \cdot U_B(a) = (w_A^1 u_A^1(a) + \ldots + w_A^n u_A^n(a)) \cdot$$
$$\cdot (w_B^1 u_B^1(a) + \ldots + w_B^m u_B^m(a))$$

or, in vector-matrix form:

$$U_A(a) \cdot U_B(a) = \frac{1}{2} w^T C_1 w, C_1 = \begin{pmatrix} 0 & C \\ C^T & 0 \end{pmatrix}$$

where w is the vector of weights of the two parties $[w_A^1, \ldots, w_A^n, w_B^1, \ldots, w_B^m]$, and C is the matrix obtained by multiplication of the vectors of the scores of alternative a:

$$C = u_A(a) \cdot u_B(a) =$$
$$\begin{bmatrix} u_A^1(a) \\ \vdots \\ u_A^n(a) \end{bmatrix} \begin{bmatrix} u_B^1(a) \ldots u_B^m(a) \end{bmatrix}$$

The search for optimal weights of the objectives of both parties is a quadratic maximization problem:

$$Max(w) \ \frac{1}{2} w^T C_1 w$$

Subject to the following constraints:

(1) $$w_{Amin}^i \leq w_A^i \leq w_{Amax}^i, i = 1, \ldots, n$$
$$w_{Bmin}^j \leq w_B^j \leq w_{Bmax}^j, j = 1, \ldots, m$$

(2) The sum of the weights of the objectives of each party sum up to one:

$$\sum_{i=1}^{n} w_A^i = 1; \sum_{j=1}^{m} w_B^j = 1$$

(3) Overall utility of a party is greater than or equal to the utility of that party assured by a reference alternative:

$$\begin{bmatrix} U_A^T(a) & 0 \\ 0 & U_B^T(a) \end{bmatrix} \geq \begin{bmatrix} U_A^{Ref}(a) \\ U_B^{Ref}(a) \end{bmatrix}$$

If there is a feasible solution to this optimization problem, the alternative a will become the new reference alternative, and in case there are no new proposed alternatives, it will be the final negotiation resolution.

7. EXPERIMENTAL EVALUATION

Concepts of the NSS were tested in two types of simulation experiments. The first was performed as simulated negotiations with real actors who played a 'negotiation game' based on a case study. Half of the participants performed the exercise with the NSS and the other half without, and the results were compared and statistically analyzed. These exercises were limited by the feasible duration of the 'game' and by the computer skills of the participants, so that the efficiency of only a part of the NSS features could have been assessed.

The second type of experiments were performed with simulated actors in which the initial preference structures were obtained from 'random participants' not related to the research, while the remaining dynamics in the systems of preferences of the 'negotiating parties' was simulated by the researcher. The aim of these experiments was to test and explore in detail the role and capabilities of WAS within the framework of the NSS, which was not possible in simulations with real actors.

8. SUMMARY AND CONCLUSIONS

The Negotiation Support System is designed to assist parties involved in a dispute over international (shared) water resources, with a real or potential water scarcity. It utilizes an economic perspective, which is accepted as a rational criterion for management of scarce resources. The NSS introduces an economically based water allocation optimization model (WAS) into negotiations, with the aim of emphasizing the potential gains to all parties which can result from relating to water in terms of values and not only quantities. We believe that the WAS model, by which the parties can explore the effects of various domestic and international water allocation schemes, contributes to their creativity in searching for alternative negotiation solutions.

The NSS includes tools based on the concepts of multi-criteria decision making that enable the negotiating parties to evaluate their systems of preferences and recognize opportunities for trade-off between differently valued objectives and for joint gains.

The parties to negotiation over international waters often tend to lack mutual confidence, which causes them to consider distributive solutions. The proposed protocol of interaction and the iterative manner of negotiation are designed to improve the interaction between the parties and assist them in gradually advancing from distributive win-lose alternatives to alternatives which bring joint gains. The combination of the AHP model for individual decision support and the Nash bargaining solution enables the parties to recognize mutually preferred alternatives, which might otherwise be overlooked.

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