Strategic Decision Support for Resolving Conflict over Water Sharing among Countries along the Syr Darya River in the Aral Sea Basin

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Abstract: The graph model for conflict resolution (GMCR), along with its associated decision support system GMCR II, are employed for systematically studying the strategic aspects of conflict existing among countries in the Aral Sea Basin of Central Asia. Competition for water is increasing in the central Asian countries in the Aral Sea Basin since they became independent in 1991. Disputes have developed between the three downstream countries, Kazakhstan, Turkmenistan, and Uzbekistan, and the two upstream countries, Kyrgyzstan and Tajikistan, in the basin in sharing water in its two main rivers, Syr Darya and Amu Darya. The downstream countries are heavy consumers of water for growing cotton while the upstream countries want to use more water for electricity generation and farming. Accordingly, GMCR II is utilized as a formal mechanism for better understanding the complex conflict existing at present among countries along the Syr Darya and for providing insights as to how these countries may interact with one another in attempting to reach a resolution acceptable to all. In particular, strictly following the present water allocation agreement by all parties is found to be the most preferred resolution for both the upstream and downstream countries.

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Introduction

The Aral Sea Basin, depicted in Fig. 1, is situated in the heart of the Eurasian continent, and extends over the territories of the five central Asian republics: Kazakhstan, Turkmenistan, Kyrgyzstan, Tajikistan, and Uzbekistan. Portions of the basin lie in Afghanistan, China, and Iran. There are two main rivers flowing into the Aral Sea: The Amu Darya, which originates in the mountains of Afghanistan and Tajikistan and flows through Turkmenistan and Uzbekistan to the Aral Sea, and Syr Darya, which starts in Kyrgyzstan and flows through Tajikistan, Uzbekistan, and Kazakhstan to the Aral Sea (Vinogradov and Langford 2001).

The Aral Sea has shrunk rapidly since 1960 as agricultural demands have deprived this large central Asian lake of sufficient water to sustain it. Thus, it became a saltier lake after the 1960s. Uzbekistan, Kazakhstan, and other central Asian states use this water to grow export crops, mainly cotton, in the face of widespread environmental consequences, such as fisheries loss, water and soil contamination, and dangerous levels of polluted airborne sediments. Though the current situation is unsustainable, the poverty and export dependency of the central Asian states have prevented any remedial action, and the sea continues to shrink in size (Dukhovny and Sokolov 2002).

The Aral Sea is one of the greatest environmental catastrophes ever recorded. Inflows to the Aral Sea Basin have been provided for thousands of years, by its two major rivers, the Amu Darya and the Syr Darya. The irrigated agriculture in the basin was conducted at a sustainable level at the beginning of the 20th Century. After the Russian Empire was replaced by the Soviet Union, this started to change. Soviet planners were not interested in traditional agricultural practices and sought products that could be exported for hard currency. They placed cotton high on their list and the Soviet Union became a net exporter of cotton in 1937. From 1940 to 1980, Soviet cotton output rose from 2.24 to 9.1 million tons. Most of this cotton came from Uzbekistan, Turkmenistan, and Tajikistan, which together accounted for nearly 90% of the entire Soviet crop (Critchlow 1991). Change accelerated in the 1950s, as irrigated agriculture in central Asia was expanded and mechanized. Starting in 1960, large amounts of water from the rivers were diverted for irrigating millions of hectares of land (Dukhovny and Sokolov 2002). As a consequence, after 1960, the level of the Aral Sea began to drop. Although the sea had been receiving about 50 km^3 of water per year in 1965, by the early 1980s this had fallen to zero. As the Aral Sea shrank, its salinity increased, and this resulted in a considerable decline in the formerly large fish catch. The declining sea level lowered the water table in the region, destroying many oases near its shores. The diversion of water to irrigated agriculture had other detrimental effects as well. Much of the ecologically sensitive land in the river deltas was converted to cropland, and pesticide use was heavy throughout the Aral Sea Basin, resulting in heavy contaminant concentrations in the sea. Further, overirrigation caused salt buildup in many agricultural areas. Overall, dependence upon the monoculture of cotton had adverse consequences not only upon

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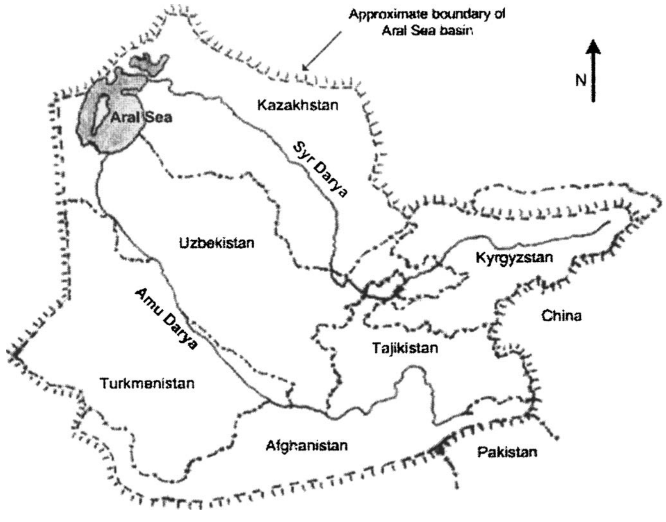

Fig. 1. The Aral Sea Basin

agriculture and the environment but also upon industry, education, health, and, ultimately, public morality (Rumer 1989).

By the beginning of the 1990s, the surface area of the Aral Sea had shrunk by nearly half, and the volume was reduced by 80% (Horsman 2001). Many secondary effects began to appear. The regional climate became more continental, shortening the growing season and causing some farmers to switch from cotton to rice, which demanded even more diverted water. The exposed area of former seabed was now over 28,000 km^2 from which winds picked up millions of tons of sediments laced with salts and pesticides, with devastating health consequences for the surrounding regions.

In 1988, the Soviet Union decreed that cotton growing was to be reduced, expecting the Aral Sea to receive water in gradually increasing amounts. This caused some reduction in water diversion. However, the dissolution of the Soviet Union in 1991 ended such central authority and the Aral Sea crisis has been in the hands of the five central Asian independent nations, Uzbekistan, Kazakhstan, Turkmenistan, Tajikistan, and Kyrgyzstan. Since this change, water use has increased rapidly and is now at an unsustainable level. For example, between 1995 and 2000, irrigated land increased by 7% throughout central Asia (ICG 2002). During the Soviet era, water and energy resources were exchanged freely across what were merely administrative borders. However, the five central Asian states have failed to come up with a viable regional approach to replace the Soviet system of management due to competition among themselves. Arriving at such an agreement was difficult due to the power imbalance among the five states and the unwillingness of the states to cooperate.

An annual cycle of disputes has developed between the three downstream countries—Kazakhstan, Turkmenistan, and Uzbekistan—all heavy consumers of water for growing cotton, and the upstream nations—Kyrgyzstan and Tajikistan. The downstream countries require more water for their expanding agricultural sectors and rising populations, whereas the economically weaker upstream countries are trying to win more control over their resources and want to use more water for electricity generation and farming (ICG 2002; McKinney 2003; Antipova et al. 2002). Further information about the water sharing problem in the Aral Sea Basin is provided by Micklin (2000) and Weinthal (2002).

In 1992, the five states in the Aral Sea Basin established an intergovernmental body, the Interstate Coordinating Water Commission (ICWC) to manage water resources in the Aral Basin (Dukhovny and Sokolov 2002). ICWC focuses almost exclusively on the division of water. Nonetheless, it has failed to take into account changing political and economic factors. It has no representation from agricultural or industrial consumers, nongovernmental organizations or other parties. Additionally, its management is dominated by Uzbekistan, leading to suspicions that it favors that country's national interests. This has reduced political commitment by other countries to the commission, resulting in a serious shortage of funds. In the meantime, the individual countries have done little to contribute to the maintenance of water systems that benefit the region.

Western donors have started to develop other management systems such as the Global Environment Facility program, in coordination with the International Fund to Save the Aral Sea (Dukhovny and Sokolov 2002). The United Nations (UN) supported Special Program for the Economies of Central Asia is also working on water management (ICG 2002). However, none of these initiatives has made much headway in confronting the key political obstacles, especially the unwillingness of the states to cooperate. One international project that did produce some real benefits was the USAID-funded program that helped to bring about the 1998 Syr Darya agreement on water and energy. In 1996, USAID staff assisted in the initiation of a roundtable of water officials from Kyrgyzstan, Kazakhstan, and Uzbekistan, which resulted in an agreement in 1998 that has helped lower tensions around the Syr Darya.

This paper focuses on a subsystem of the Aral Sea Basin, consisting of countries along the Syr Darya, and analyzes the conflict existing among them by employing the graph model for conflict resolution (Fang et al. 1993). The three Syr Darya River riparian states suffered a serious economic recession after independence and as a result, competition for water took on an added urgency in the context of economic and political fragmentation (Arnold 1996). Besides, as early as 1960 the irrigated lands in the Syr Darya River Basin was about 2.1×10^6 ha and the total diversion amounted to over 30 km^3, exceeding the flow of the river in low water years. In 1990, the irrigated area in the basin had reached 3.3×10^6 ha (Antipova et al. 2002).

The upstream country, Kyrgyzstan, trades water in the Syr Darya River to downstream Uzbekistan and Kazakhstan for energy in the form of gas, coal, or power. As energy deliveries have been unreliable, Kyrgyzstan responded by releasing more water through its hydropower dam in winter, which results in downstream flooding and less water for summer irrigation in the downstream countries. Attempts by Kyrgyzstan to demand payment for water have been resisted by the downstream countries. With independence, Uzbekistan, for instance, found itself suddenly dependent on food imports as its self-sufficiency in food had been compromised by the predominance of cotton production in the republic. In order to procure these food items in world markets, the government needed hard currency and obtaining hard currency required the continuing maintenance of a cotton monoculture (Seiko 1998). Food shortages brought socioeconomic strain to the region, but the country's continuing demand for large amounts of water in order to grow cotton instigated international political tensions. The report of the International Crisis Group (ICG 2002) provides many examples of conflicts over the sharing of water that have arisen among the countries along the Syr Darya River.

As each country has started to view the problem as a zero-sum game, it has taken steps to increase control over water, often to the detriment of the other countries. Unfortunately, the ICWC, an intergovernmental body set up in 1992 for the management of water in the basin, was not successful in resolving conflicts among the member countries (ICG 2002).

The decision support system, called graph model for conflict resolution (GMCR) II (Fang et al. 2003a,b; Hipel et al. 1997, 2001; Kilgour et al. 2001), developed for implementing the graph model for conflict resolution, is used to rigorously analyze the conflict. In the next section, the importance of strategic decision making is pointed out, an explanation of relationships between game theory and the graph model for conflict resolution are explained, and an overview of GMCR II is presented. Subsequently, GMCR II is employed to systematically investigate the water sharing conflict existing in the Syr Darya River Basin in order to obtain strategic insights and guidance for enhanced decision making. Individuals or organizations possessing specialized or confidential knowledge about this conflict or other related disputes in the Aral Sea region, are encouraged to carry out their own strategic analyses based on models reflecting their comprehension of various conflict situations.

Studying Strategic Disputes

Multiple Participant–Multiple Objective Decision Making in Water Resources

By definition, conflict over water involves more than one decision maker, participant, or stakeholder. For instance, water conflicts occurring in drainage basins located throughout the world concern many different interest groups, such as national and regional governments, city councils, nongovernmental organizations, environmentalists, many kinds of industries, agriculture, and individual citizens (Wolf 2002). Because water can be used for multiple purposes, often a given interest group is directly associated with a specific use of water. Hence, farmers, the tourist industry, city dwellers, the shipping industry, and electrical utilities, would like to see water be primarily utilized for irrigation, recreation, human consumption, navigation, and generation of hydroelectrical power, respectively. Whatever the case, there is almost always disagreement among people and organizations over how water should be utilized in a sustainable fashion that is fair to all of the stakeholders (Gleick 1993). Accordingly, techniques from game theory or multiple participant—multiple objective decision making, as well as other related systems analysis techniques (Nandalal and Simonovic 2003), have great potential for assisting in systematically modeling and analyzing conflicts over water so that disputes can be better understood and discussed in the process of achieving enhanced decisions for everyone concerned. In fact, as is argued by Hipel and Fang (2005), game theory methods have a key role to play in studying both technological and societal systems since conflict and associated value systems constitute inherent components of environmental (natural world), societal (real life), intelligent (artificial life), and integrated (mixed life) systems. An overview of game theory methods is furnished next, while a systematic procedure for applying the graph model to actual disputes over water and other issues is given thereafter.

Game Theory

Game theory constitutes a field of study in which formal mathematical models are developed for modeling and analyzing a range of different types of games or conflicts. Although the mathematical study of games can be traced back to the 17th Century when European mathematicians analyzed parlor games such as poker and roulette, the significant breakthrough arrived with the publication of the landmark book by Von Neumann and Morgenstern on "The Theory of Games and Economic Behavior" in 1944. The different techniques first presented in the book of Von Neumann and Morgenstern are often referred to as classical game theory methods. The game models include the normal and extensive forms of the game, which fall under a branch of game theory called noncooperative game theory, as well as the characteristic function form of the abstract game model, which comes under the umbrella of cooperative game theory.

Over the years, game theorists have developed very sophisticated mathematical models and have defined very precisely what they mean by various game theory models. In fact, some game theorists feel that a unique group of techniques that encompasses metagame analysis (Howard 1971), conflict analysis (Fraser and Hipel 1984), drama theory (Howard 1999), and the graph model for conflict resolution (Fang et al. 1993) are not part of classical game theory as the way in which these models are defined is radically different from classical game theory. For instance, these methods usually assume that only relative preferences are known for each decision maker among the possible states or scenarios that could occur in a conflict whereas classical game theory techniques usually assume that cardinal preferences such as cardinal utility values or the worth of states in monetary terms are given. Moreover, the metagame-type approaches allow one to investigate how a game could be played as it evolves over time, whereas classical game theory methods usually require a user to specify all possible strategy sequences that could occur before the actual onset of the game. Whatever the case, all methods dealing with the modeling of conflict assume that there are two or more decision makers each of whom can have one or more objectives. If one assumes these qualifications as being necessary to become a member of the game theory club, all of the foregoing techniques could be classified as being part of game theory.

When investigating the physical aspects of a specific engineering problem, such as the pollution of an underground aquifer by carcinogenic substances, scientists and engineers usually employ a range of different kinds of formal physical models expressed mathematically. Likewise, when studying the social, political, and economic characteristics of, say, a water pollution problem, analysts usually employ a wide variety of tools from fields such as systems engineering, systems analysis, operational research, statistics and game theory to better understand the social world of human decision making and conflict [see Hipel et al. (1999) for a summary and comparison of decision-making tools from operational research and systems engineering and Hipel (2002a,b) for an overview of conflict resolution procedures and tools for use in life support systems analysis, as described in the Conflict Resolution Theme (Theme 1.40) in the Encyclopedia of Life Support Systems]. Therefore, analysts should have a large tool box at their disposal that is subdivided into physical and societal modeling sections [refer to Hipel et al. (2007) for an overview of decision support systems for investigating physical and societal systems problems in water resources management]. Game theory tools can be ideal for capturing the multiple participant–multiple objective features of the overall pollution problem. Moreover, these game theoretical methods may be employed within general procedures for carrying out negotiation and conflict resolution such as approaches put forward by Fisher and Ury (1981), De Bono (1985), Bazerman and Neale (1993), Lewicki et al. (1994), Zartman (1994), Hampson (1995), and Raiffa et al. (2002). Finally, Thiessen and Loucks (1992) provide an insightful taxonomy for categorizing negotiation support systems for application in water resources management and elsewhere.

The graph model for conflict resolution is especially useful for investigating strategic aspects of decision making under conflict. When combined with techniques from economics and hydrology, cooperative game theory can be employed for equitably allocating a resource such as water among competing uses and users [see, for instance, Wang et al. (2003, 2007) for illustrative applications and references to other research dealing with water allocation]. The extensive form of the game can be utilized for investigating enforcement of environmental regulations [refer to Kilgour et al. (1997), and references cited therein].

The graph model for conflict resolution constitutes an improvement and extension of conflict analysis (Fraser and Hipel 1984), which in turn is an enhancement of metagame analysis (Howard 1971) and also has advantages over drama theory (Howard 1999). More specifically, the graph model can take into account irreversible moves in which movement is allowed only in one direction. When, for instance, a body of water, such as the Aral Sea, is severely polluted, the damage incurred cannot be immediately reversed. The graph model can also handle common moves in which two or more decision makers can cause a conflict to change from one state to the same state. Additionally, as is summarized in Table 4, the graph model can take into consideration a rich range of different types of human behavior under conflict when stable states for a given decision maker as well as equilibria or compromise resolutions are determined. The graph model has also been expanded for use in coalition analysis (Kilgour et al. 2001). Finally, as discussed in the next section, the graph model methodology has been implemented as a comprehensive decision support system for application to real world disputes.

Applying the Graph Model for Conflict Resolution

The graph model for conflict resolution (Fang et al. 1993) is founded upon a rigorous mathematical framework, utilizing concepts from graph theory, set theory and logic—the mathematics of relationships. Hence, its design is mathematically based yet completely nonquantitative in nature. From a theoretical viewpoint, within the paradigm for the graph model for conflict resolution, each decision maker has a directed graph that records each unilateral move that he or she can take to move the conflict from one state to another. This format permits the existence of irreversible moves whereby movement can only take place in one direction. For instance, when a company illegally dumps toxic pollutants on its premises and thereby allows these pollutants to leach into the underground aquifer, the environmental damage cannot be immediately reversed. Detailed mathematical definitions for the graph model and its associated implementation algorithms are available in the published literature (Fang et al. 1993, 2003a,b).

Fig. 2 presents the general procedure (Fang et al. 1993) for applying the graph model approach to conflict resolution to actual disputes. Real-world strategic conflicts may be confusing and difficult to comprehend initially. Nonetheless, by systematically applying the modeling and analysis stages shown in Fig. 2, it is possible to understand and analyze even very complex conflicts, and foresee possible resolutions.

The decision support system GMCR II (Fang et al. 2003a,b; Hipel et al. 1997, 2001; Kilgour et al. 2001; Li et al. 2004) permits the graph model methodology summarized in Fig. 2 to be conveniently employed in practical applications, such as conflict arising over proposed exports of water in bulk quantities from Canada (Hipel and Fang 2005) and the ongoing global conflict taking place with respect to trade versus the environment (Hipel and Obeidi 2005). As the above references provide comprehensive descriptions of GMCR II, this paper does not describe it in detail. Fig. 3 shows the overall design of GMCR II, which has been developed within a Windows environment.

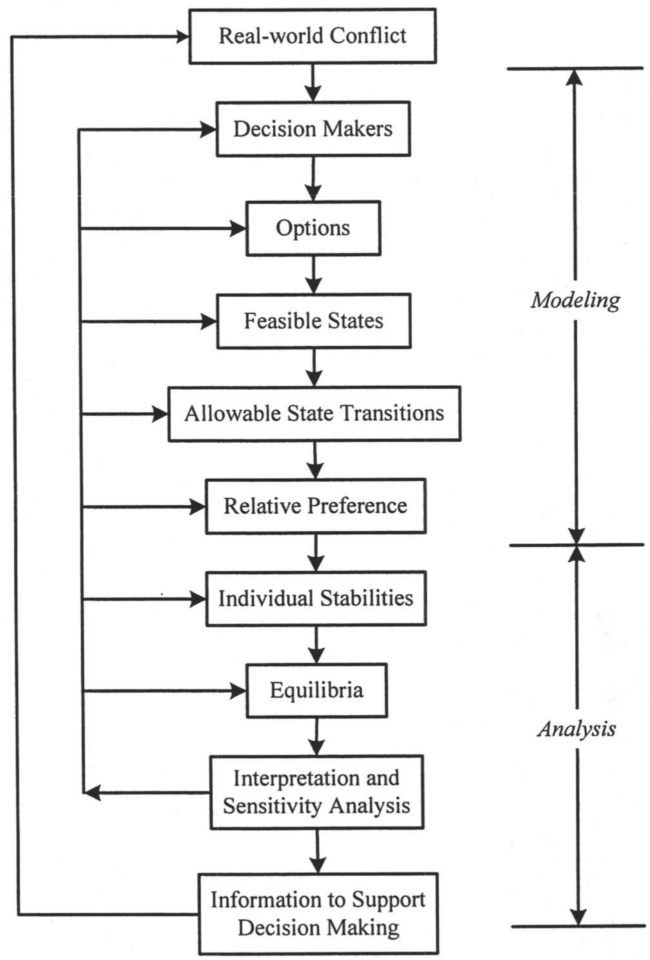

Fig. 2. Applying the graph model for conflict resolution

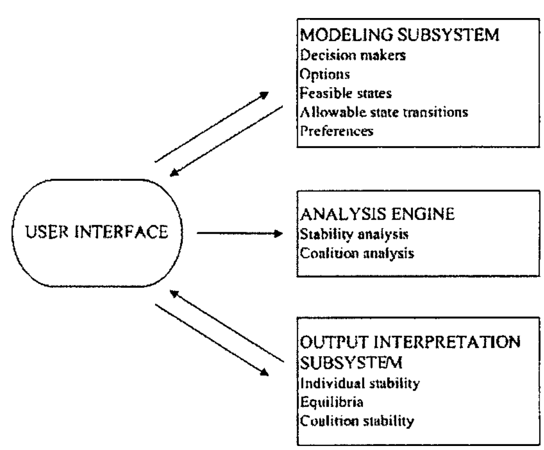

Fig. 3. GMCR II structure

Table 1. Decision Makers and Their Options in the Syr Darya River Water Sharing Conflict

Decision maker		Action
Downstream	Uzbekistan and Kazakhstan[a]	**1. Less fuel**: Supply less fuel than specified.
Two downstream countries		**2. Pressure**: Exert political and military pressure.
		3. Follow agreement: Follow the present agreement.
Upstream	Kyrgyzstan[b]	**4. Ignore agreement**: Generate more hydroenergy in winter than agreed upon.
One upstream country		
		5. Follow agreement: Do not release too much water for hydropower generation during winter and release sufficient water for irrigation during summer.
		6. Revise agreement: Revise agreement to meet winter hydropower demand and allow for summer irrigation.
ICWC		**7. Enforce agreement**: Enforce the present agreement.
	Interstate Commission for Water Coordination	**8. Revise agreement**: Revise agreement to try to meet new demands of both upstream and downstream countries.

[a]Needs water for irrigation.

[b]Requires water for generating power.

As can be seen by comparing Figs. 2 and 3, GMCR II permits the main steps in a conflict resolution study to be applied to actual real world disputes. In fact, the decision support system GMCR II is a negotiation preparation system that adapts the graph model for conflict resolution to the modeling and analysis of real-world conflicts in diverse fields such as water resources, international trade, politics and military science. Within this paper, GMCR II is employed for the first time to investigate strategic conflict between countries along the Syr Darya River in the Aral Sea Basin. The various steps shown in Figs. 2 and 3 are explained using the application. In particular, some components of the modeling subsystem of GMCR II are illustrated using the conflict in sharing water in the Aral Sea Basin in the next section, where special emphasis is placed on elicitation of preference information. The analysis engine of GMCR II shown in Fig. 3 calculates stability results for a range of solution concepts (representations of human behavior under conflict) for each decision maker, for every state or scenario, as is illustrated in the section entitled "Analysis and Results: Deciding What To Do."

Modeling: Putting the Problem into Perspective

As mentioned earlier, this paper focuses on the strategic conflict over water allocation in the Syr Darya River Basin. The study is carried out in isolation of the issue of water allocation in the Amu Darya River Basin, which is formed by the other major river that flows into the Aral Sea. Additionally, the conflict centers on the controversy over water allocation and does not take into account environmental problems that are common to the entire Aral Sea Basin. Hence, a strategic solution with respect to one localized dispute may not be optimal for the entire region. Readers who are interested in examining the overarching strategic conflict existing in the Aral Sea Basin could do so by employing the conflict methodology utilized in this research. In fact, in many resource conflicts taking place in the real world, there are often many interconnected disputes taking place simultaneously, each of which can be examined in detail and also as a whole.

GMCR II is utilized in this section to formally model the conflict over the sharing of water by countries in the Syr Darya River Basin by following the steps shown in Figs. 2 and 3. The next section explains how this conflict can be rigorously analyzed and how strategic insights can be garnered.

Decision Makers and Options

As indicated in Fig. 2, identifying the decision makers and options in a conflict study is the first step in gathering information to understand the conflict better and to make it amenable to systematic modeling and analysis. Decision makers should have the ability to make decisions that can directly bear upon the eventual resolution of the dispute. Options are specific actions that can actually occur in a conflict. Each decision maker can select which options to implement during the evolution of the conflict.

As explained in the first section, the three decision makers in this model are:

- *Downstream countries*: Uzbekistan and Kazakhstan are the two downstream countries along the Syr Darya River in the Aral Sea Basin. These two nations need water for irrigation purposes but encounter water shortages during the cropping season. Moreover, these states are economically stable and politically powerful compared to the upstream country.
- *Upstream country*: Kyrgyzstan is the upstream country on the Syr Darya River in the Aral Sea Basin and requires water for generating power by releasing water from the Toktogul Reservoir.
- *ICWC*: This intergovernmental body was set up in 1992 for the management of water in the Aral Sea Basin (ICG 2002).

Table 1 lists the decision makers and their options in the Aral Sea dispute. As depicted in Fig. 2, a conflict model can be updated at any time during the modeling and analysis process to reflect the obtaining of more information about the conflict or a better understanding of the true situation. One could, for instance, decide to include more decision makers in the conflict model such as the Interstate Council for Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan, which in coordination with USAID have played a role in trying to prevent conflict in the Aral Sea region. Nonetheless, the writers have elected to study as simple a conflict model as possible of the Syr Darya River Basin conflict over water allocation, in order to effectively obtain basic strategic insights into

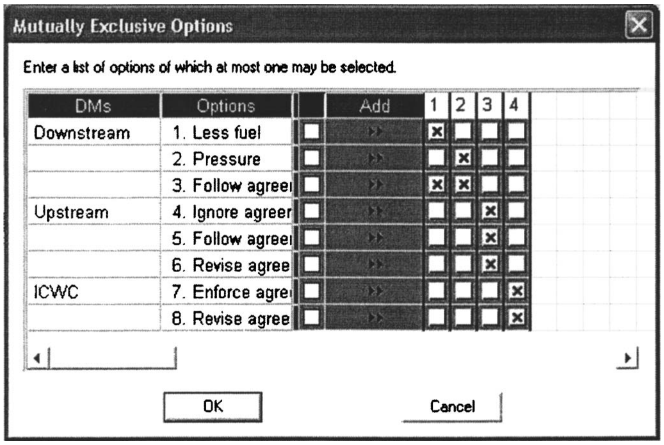

Fig. 4. Mutually exclusive options

the underlying dispute. The writers believe that, at its core, the dispute involves three key decision makers and, therefore, they concentrate on investigating this fundamental parsimonious game. Of course, readers who are knowledgeable about other information regarding this dispute are encouraged to execute their own investigation employing a more complicated game model. In view of the fact that every model is constructed as a simplification of reality so that the problem at hand can be more easily understood and put into proper perspective, the writers feel that adhering to the principle of Occam's Razor, which advocates model parsimony, is often the most informative path to follow [see Sec. 1.3.1 in Hipel and McLeod (1994) for a discussion of Occam's Razor]. Adding additional parameters to a model to ascertain how strategic results are affected can be carried out using sensitivity analyses.

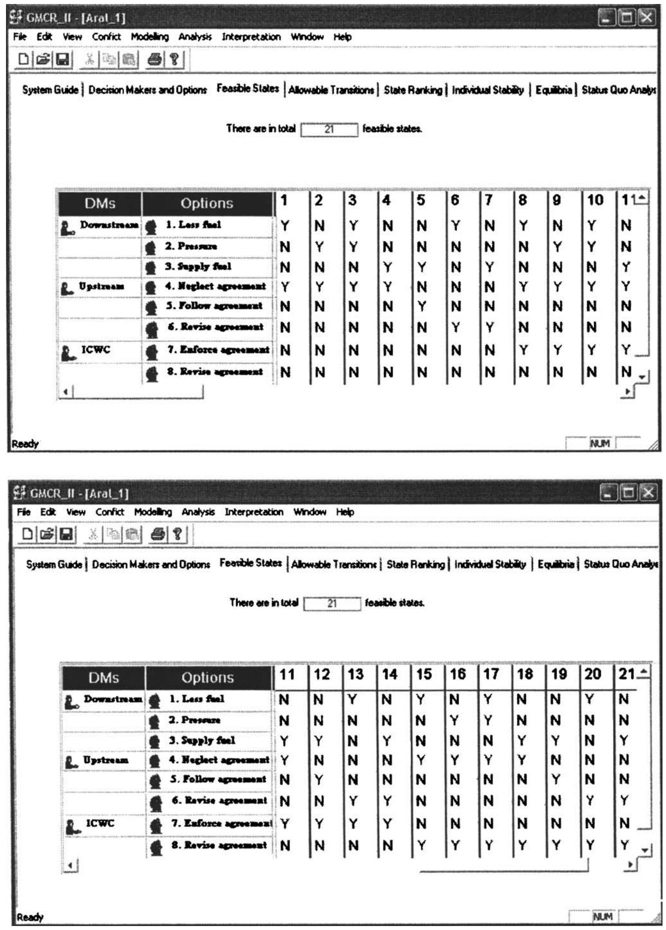

Fig. 5. Feasible states for the model

Feasible States

Because the model in Table 1 contains 8 options, each of which can be selected or not, mathematically there are $2^8=256$ possible states. However, not all combinations of options are feasible in practice and of those that are feasible, not all are distinguishable. Subsequent to entering the decision makers and options, the user of GMCR II must identify the infeasible states, which GMCR II will remove from the model, and the groups of states that are effectively identical, which GMCR II will combine into a single state. These steps enable GMCR II to list all states that can actually occur in the model. In the model of the Syr Darya River water sharing conflict, there are only 21 feasible states, which is much less than the total number of mathematically possible states.

GMCR II contains four dialog boxes for identifying infeasible states, which are removed from the model before state transitions and preferences are considered. Fig. 4 shows the dialogue box for selecting the mutually exclusive options. Similarly, the model has dialogue boxes for selecting "at least one option" and "option dependence." In the Aral Sea model, the three options under the control of the upstream countries are mutually exclusive and, hence, these countries can only select at most one of their three options, which are numbered as Options 4, 5, and 6 in Fig. 4. Thus, if the upstream countries were to "ignore agreement" (Option 4), their other two options of "follow agreement" (Option 5) and "revise agreement" (Option 6) could not occur. Likewise, Options 7 and 8 are mutually exclusive for ICWC as it only makes sense to choose, at most, one of those two options. Therefore, for example, if the ICWC were to "enforce agreement" (Option 7), it would not "revise agreement" (Option 8), and vice versa. For the downstream countries, the first and third options and second and third options are mutually exclusive. For example, if downstream countries exert "pressure" (Option 2) they will not "follow agreement" (Option 3) but they may supply "less fuel" (Option 1). The X's that are entered in a given column in Fig. 4 designate which options are mutually exclusive. Moreover, at least one of the three options for the downstream countries and for the upstream nations must be taken. (An illustration indicating this is not provided in this paper).

After GMCR II removes the infeasible states, the remaining feasible states are listed as columns of Y's and N's, where "Y" indicates "yes," the option opposite the Y is selected by the decision maker controlling it, and "N" means "no," the option is not taken. The 21 feasible states for the Aral Sea dispute are listed in Fig. 5. For convenience, each state is assigned a number. For example, Fig. 5 shows that at State 5, the downstream countries (called Downstream) select its third option, but not its first or second option, to form its strategy NNY. At State 5, the upstream country (Upstream) has taken Option 5, but not 4 and 6, and, therefore, has adopted its strategy NYN. Finally, the ICWC has not chosen any of the options, so has followed the strategy NN. When strategy selections of all decision makers are combined, State 5, or (NNY NYN NN), written horizontally in text, is the result.

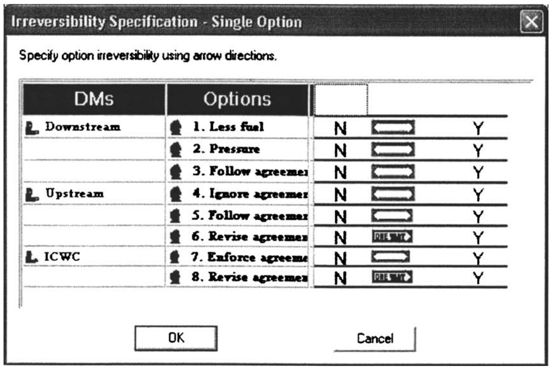

Fig. 6. Specification of irreversible options for the model

Allowable State Transitions

At any state of a conflict model, a particular decision maker may be able to unilaterally cause a transition to another state by changing his or her option selection. For example, by changing from N to Y for Option 8, ICWC can cause a state transition from (NNY NYN NN), State 5, to (NNY NYN NY), State 19.

GMCR II automatically calculates all possible state transitions, if any, from each state for each decision maker. However, some transitions may be infeasible. This occurs, for instance, when an option is irreversible—after the option is selected, it cannot be undone. For instance, the aforementioned transition from State 5 to State 19 is modeled as irreversible, reflecting the assumption that ICWC cannot reverse the decision taken to revise the agreement. Fig. 6 illustrates how irreversible options are entered into GMCR II. For example, the arrow pointing to the right beside Option 8 means that only change in the selection of Option 8 is permitted from N to Y. The same is also true for Option 6, whereas all options other than 8 and 6 are reversible.

Relative Preferences

Often, the most difficult hurdle in developing a decision model is procuring accurate preference information. An extraordinary advantage of GMCR II is that it requires only relative preference information over states. In other words, the analyst must specify each decision maker's ordering of the states, with ties allowed; there is no need to estimate the amount or intensity of any preference. Thus, cardinal preference information, such as utility values, is not required; the user of GMCR II enters only information that permits GMCR II to determine a ranking of states from most to least preferred for each decision maker, where some states may be equally preferred.

GMCR II elicits relative preference information for a particular decision maker via two quick methods, option weighting and option prioritizing. Option prioritizing is simple to use in practice and orders states according to the truth or falsity of prioritized logical statements about which options are selected. Table 2 presents the preference statements in order of priority for each decision maker, from most important at the top of a column to least important at the bottom. The reader should keep in mind that the numbers in Table 2 refer to option numbers and not state numbers.

Consider the preference statements for downstream given in the left-hand column in Table 2. Option 5 located at the top of the first column means that downstream most prefers to see upstream follow the agreement. As indicated by Option 3 written below the 5, downstream's next preference is for itself to follow the agreement. In order of decreasing preference, downstream would like to supply less fuel (Option 1), followed by exert pressure (Option 2). Next, downstream would like upstream not to ignore the present agreement, as indicated by the negative sign in front of Option 4. Then, downstream does not want to see upstream or ICWC revise the agreement (−6|−8, where the vertical bar means "or"). Finally, downstream would like ICWC to enforce the agreement (Option 7).

Table 2. Lexicographic Preference Statements for the Decision Makers Expressed in Terms of Options

Downstream	Upstream	ICWC
5	5	3 and 5
3	3	8|6
1	4	7 IF 1|2
2	6|8	−4
−4	7	−1|−2
−6|−8	−1	
7	−2	

Note: |=or

The middle column of Table 2 lists upstream's preference statements. As can be seen, it most prefers to follow the present agreement (Option 5). Next, it prefers downstream to follow the agreement (Option 3). The third-level preference is for it to ignore the agreement (Option 4). Subsequently, upstream wishes to see it revise the agreement or ICWC change the agreement (6|8). This is followed by ICWC enforcing the agreement (Option 7). Downstream not supplying less fuel (−1) followed by not exerting force (−2) are the least preferred preference statements.

As indicated in the third column from the left in Table 2, ICWC most prefers to see downstream and upstream follow the agreement options (3 and 5). Then, it likes to revise the agreement or see downstream change the agreement (8|6). Next, ICWC prefers to enforce the agreement if downstream supplies less fuel or exerts pressure (7 if 1|2). Subsequently, ICWC does not like upstream to ignore the agreement (−4). Finally, ICWC does not want downstream countries to supply less fuel or exert pressure (−1|−2).

A remarkable advantage of the option prioritization approach to preference elicitation is that it closely reflects the way in which a person thinks about preferences in a given dispute. In reality, one can very easily and expeditiously obtain prioritized preference statements in terms of options for a decision maker, either directly from the decision maker or from published descriptions of the conflict as is done in this paper. What clients find to be stunning about the graph model methodology is that relative preference information can furnish detailed and accurate analytical results, such as the potential resolutions to the conflict under study.

When employing GMCR II, a user only needs to enter known preference statements expressed in terms of options for a given decision maker. In fact, these preference statements adhere to all of the rules of first order logic. Assuming transitivity of preferences, GMCR II possesses an algorithm for taking the prioritized preference statements for each decision maker to produce a ranking of states for each decision maker in which ties are permitted. Often, a given decision maker's most and least preferred preference statements are initially known. After GMCR II ranks the states based on a limited number of preference statements, there may be blocks of equally preferred states contained within the ordering of states. As more preference information becomes avail-

Table 3. Ranking of States for Decision Makers

Downstream countries	Upstream countries	ICWC
12	19	21
19	12	14
5	5	7
14	18	19
7	11	18
21	4	12
11	14	5
18	21	11
4	7	4
10	16	13
3	15	20
17	17	6
13	9	15
6	8	16
20	10	17
8	2	9
15	1	8
1	3	10
9	13	2
16	20	1
2	6	3

able, these equally preferred blocks will become less prevalent and will fully disappear when there are sufficient preference statements to produce complete ranking of states from most to least preferred with no ties. However, even when there are blocks of equally preferred states for one or more decision makers, GMCR II can still carry out stability analyses. In practice, this means that one can commence with a "quick and dirty" analysis and subsequently refine preference statements as more information becomes available. Finally, it should be stressed that a user only has to supply preference statements in terms of what is usually not a large number of options. The user does not have to order the states, which in some cases can be relatively large—GMCR II expeditiously determines the ordering using the lexicographic preference statements supplied by the user. In fact, an appealing feature of the graph model methodology is that the user only needs to supply relatively small amounts of information to calibrate a conflict model upon which highly accurate analytical results can be ascertained.

Although not shown here, GMCR II can display the ranking of states, including ties, for a given decision maker using the Y-N notation, by listing the states from most preferred on the left to least preferred on the right. States that are equally preferred have the same background color. Table 3 displays the preference ranking of states from most preferred at the top to least preferred at the bottom for each of the three decision makers. In this case, there are no sets of equally preferred states for any of the three decision makers. Notice that downstream most prefers State 12, as indicated by the placement of 12 at the top of the left-hand column in Table 3, and least prefers State 2, shown at the bottom. Further, the "power" held by a participant in a dispute is reflected by the options available to the decision maker and the decision maker's preferences over states. Roughly speaking, the decision makers in the Aral Sea dispute have similar levels of political and economic power.

Analysis and Results: Deciding What to Do

After a model has been established, the analysis phase of GMCR II is invoked, as is indicated in the lower portion of Fig. 2. A GMCR II analysis includes a determination of the stability of every state, for every decision maker, under all solution concepts listed in Table 4. These stability definitions describe the patterns of interaction that a decision maker may expect. If it is not advantageous for a given decision maker to depart unilaterally from a particular state according to a given solution concept, then the state is deemed to be stable for that decision maker under that solution concept. If a state is stable according to a given solution concept, for all of the decision makers, it constitutes an equilibrium under that solution concept. It is, therefore, a compromise resolution, since no decision maker has an incentive to unilaterally move away from it. Fang et al. (1993) present mathematical definitions and comparisons as well as original references for the solution concepts given in Table 4.

Subsequent to executing a stability analysis, GMCR II can display stability results separately for each decision maker as well as the equilibria. Table 5 lists the individually stable states for the three decision makers and the equilibrium states for the Aral Sea water sharing conflict. Fig. 7 shows the equilibrium list in option form as produced by GMCR II. The meanings of the acronyms given at the bottom left in Fig. 7 are explained in Table 4.

As can be seen in Fig. 7, States 7, 14, 19, and 21 are equilibria for all of the solution concepts and, therefore, constitute strong equilibria. In all of these states, the downstream countries agree to follow the agreement and try to alleviate pressure on the upstream country. That is, Uzbekistan and Kazakhstan wish to follow the present agreement on sharing water in the Syr Darya River and

Table 4. Solution Concepts and Human Behavior

Solution concept	Stability description
Nash stability	DM (decision maker) cannot unilaterally move to a more preferred state.
General metarationality (GMR)	All DM's unilateral improvements are sanctioned by subsequent unilateral moves by others.
Symmetric metarationality (SMR)	All DM's unilateral improvements are still sanctioned even after possible responses by the original DM.
Sequential stability (SEQ)	All DM's unilateral improvements are sanctioned by subsequent unilateral improvements by others.
Limited-move stability L_h	All DMs are assumed to act optimally and a maximum number of state transitions (h) is specified.
Nonmyopic (NM)	Limiting case of limited move stability as the maximum number of state transitions increases to infinity.

Table 5. Individual Stability States and Equilibrium States

Individual stability			
Downstream countries	Upstream countries	ICWC	Equilibria
4	1	4	5
5	2	5	7
7	3	7	12
11	5	11	14
12	6	12	19
14	7	13	21
18	8	14	
19	9	15	
21	10	16	
	12	17	
	13	18	
	14	19	
	15	20	
	16	21	
	17		
	19		
	20		
	21		

receive water throughout the year according to the agreement. The upstream country agrees to either follow the agreement or revise it to suit the new requirements. Thus, Kyrgyzstan's desire to follow the agreement or revise it to satisfy its present requirements constitutes stable solutions. ICWC either revises the agreement or enforces the agreement, or does neither. Accordingly, this analysis indicates the inclination of both upstream and downstream countries, not to neglect the present agreement or exert pressure on others to obtain more water for themselves as being stable, according to all of the solution concepts.

The ranking of states in Table 3 shows that the downstream countries most prefer State 12, in which both upstream and downstream countries follow the agreement and ICWC enforces the agreement. Thus, Uzbekistan and Kazakhstan prefer to avoid conflicts over the water. Next, they prefer States 19 and 5, in which they would like both the upstream and downstream countries to

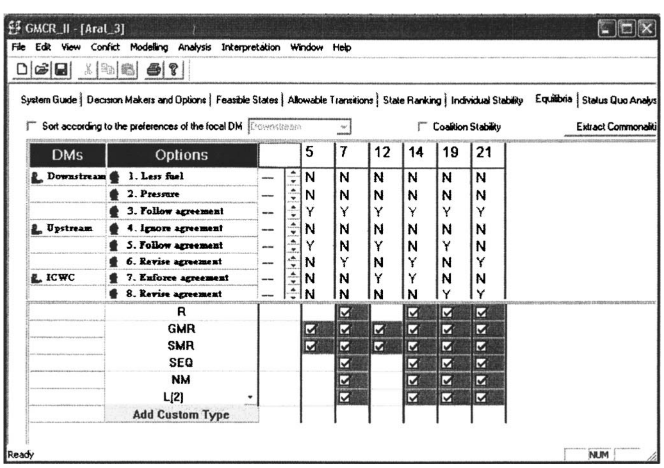

Fig. 7. Equilibrium list for the Syr Darya River water sharing conflict

Table 6. State Transitions from Status Quo to Final Outcome

	State numbers				
Transition	2		5		19
Downstream					
1. Less fuel	N		N		N
2. Pressure	Y	→	N		N
3. Follow agreement	N	→	Y		Y
Upstream					
4. Ignore agreement	Y	→	N		N
5. Follow agreement	N	→	Y		Y
6. Revise agreement	N		N		N
ICWC					
7. Enforce agreement	N		N		N
8. Revise agreement	N		N	→	Y

follow the agreement and ICWC to suggest revisions to the agreement or take no action.

The upstream country most prefers equilibrium State 19. It wants both upstream and downstream countries to follow a revised agreement of ICWC. That is, Kyrgyzstan believes that a revision of the agreement regarding the sharing of water in the Syr Darya River is necessary to cater to its present water requirements. Next, it would like ICWC to enforce the agreement and both parties to adhere to it. Its third preference is to see both the upstream and downstream countries follow the agreement without any interference from ICWC.

ICWC wishes to revise the agreement with the upstream country and see the downstream countries follow it as their best option (State 21). Next, it wants to enforce a revised agreement, followed by downstream countries following a revised agreement by the upstream country without ICWC's interference.

Table 6 shows the sequence of state transitions from the status quo State 2 to the final equilibrium State 19, where arrows indicate the location and direction of option changes during the evolution of the conflict. At the status quo, upstream Kyrgyzstan ignores the agreement and uses more water in the winter and downstream countries apply political or military pressure not to release excess water in the winter. However, attempts by the upstream countries to follow the agreement, would encourage downstream countries also to follow the agreement as shown in the joint transition from State 2 to State 5. Hence, by exhibiting a spirit of cooperation, downstream and upstream can jointly move the conflict to State 5, which is more preferred than State 3 by both decision makers. Additionally, State 5 is not a strong equilibrium since, as shown in Fig. 7, it is only an equilibrium according to the solution concepts GMR and SMR. Finally, State 19, in which both the upstream and downstream countries agree to a revised agreement could be an acceptable solution for all the parties.

Conclusions

The decision support system, GMCR II can play a supporting role in investigating the conflict among the countries along the Syr Darya River in sharing its water. As demonstrated in the study, GMCR II can provide practitioners with decision advice, structural insights and a deeper understanding of a conflict under consideration. With this enhanced understanding, practitioners can better comprehend strategic relationships among the decision makers, which can enable analysts to seize the opportunity to direct the conflict to a more favorable resolution.

To avoid confrontation by following the agreement for water allocation seems to be preferred by both the upstream country (Kyrgyzstan) and the downstream countries (Uzbekistan and Kazakhstan). The downstream countries most prefer that both the upstream and downstream countries follow the agreement and ICWC enforces the agreement. However, as water requirements have changed during the recent past, revising the agreement to suit present necessities and adhering to it, is the most preferred solution to upstream Kyrgyzstan. The ICWC also most prefers the idea of revising the agreement to suit present requirements and to have both parties follow that. An important conclusion that can be drawn from the foregoing strategic analysis is that both upstream Kyrgyzstan and downstream Uzbekistan and Kazakhstan wish to neither ignore the agreement nor exert political or military pressure over the sharing of water in the Syr Darya River as their most preferred strategy toward obtaining water.

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